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Fourth ICTP Workshop on the Theory and Use of Regional Climate Models: Applying RCMs to Developing Nations in Support of Climate Change Assessment and Extended-Range Prediction

3 - 14 March 2008

Large Scale tropical variability in AGCMs and AOGCMs

TOMPKINS Adrian Mark

the Abdus Salam International Centre For Theoretical Physics
Earth System Physics Section
Physics of Weather and Climate Group
Strada Costiera 11, P.O. Box 586, 34014 Trieste
ITALY

Large-scale variability in Atmosphere and Atmosphere-Ocean GCMs

Adrian Tompkins

Earth System Physics, ICTP, Italy

tompkins@ictp.it

Material from Julia Slingo, Thomas Jung, Gareth Berry, Chris Thorncroft, Rao and Sperber, Peter Bechtold and many others

General circulation models
Global climate models

- I will talk about results from both climate models and global NWP models (ECMWF)
- NWP models have the benefit of resolution and constant evaluation
- Both realms meet in the wrestling ring of seasonal prediction (seamless prediction)
  - NWP models tested in climate mode
  - Climate models tested in NWP mode

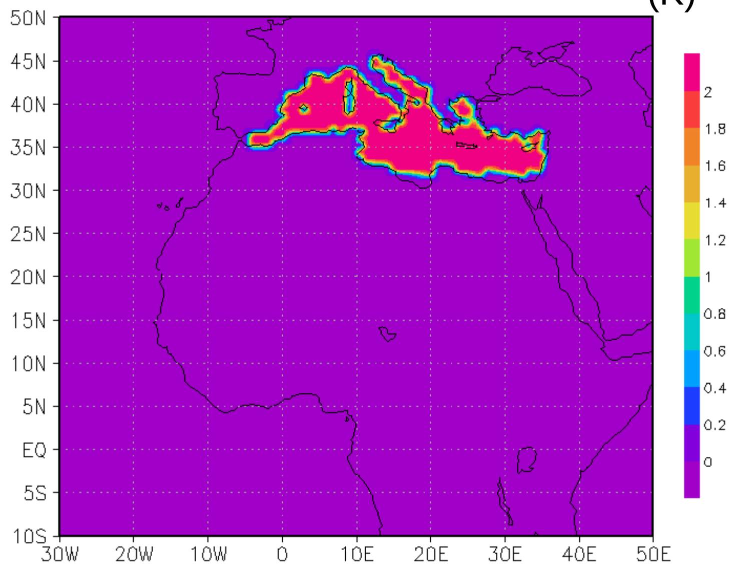
Why are we interested in global climate/NWP models (GCMs)?

- GCM provides boundary conditions for regional climate model (RCM)
- Net ascending motions (Convection) and latent heating in the RCM is constrained by
  - Radiative forcing
  - Convergence set by boundary conditions
- So! If for a given region the driving GCM under-predicts convective activity, **very likely that regional model will also under-predict convective activity**

EXAMPLE
Effect of Mediterranean SSTs on African Rainfall

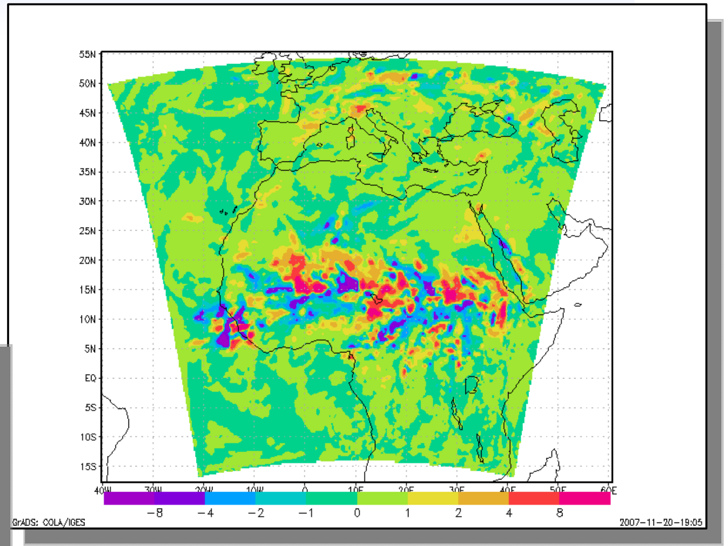
- 3 Month integration with REGCM3 regional climate model, JJA 2003
  - WARM RUN: Observed SSTs
  - COLD RUN Observed SSTs – 2.1 K
- EXPECT: warm run to have increased rain over Sahel as seen in observations and 3 GCMs

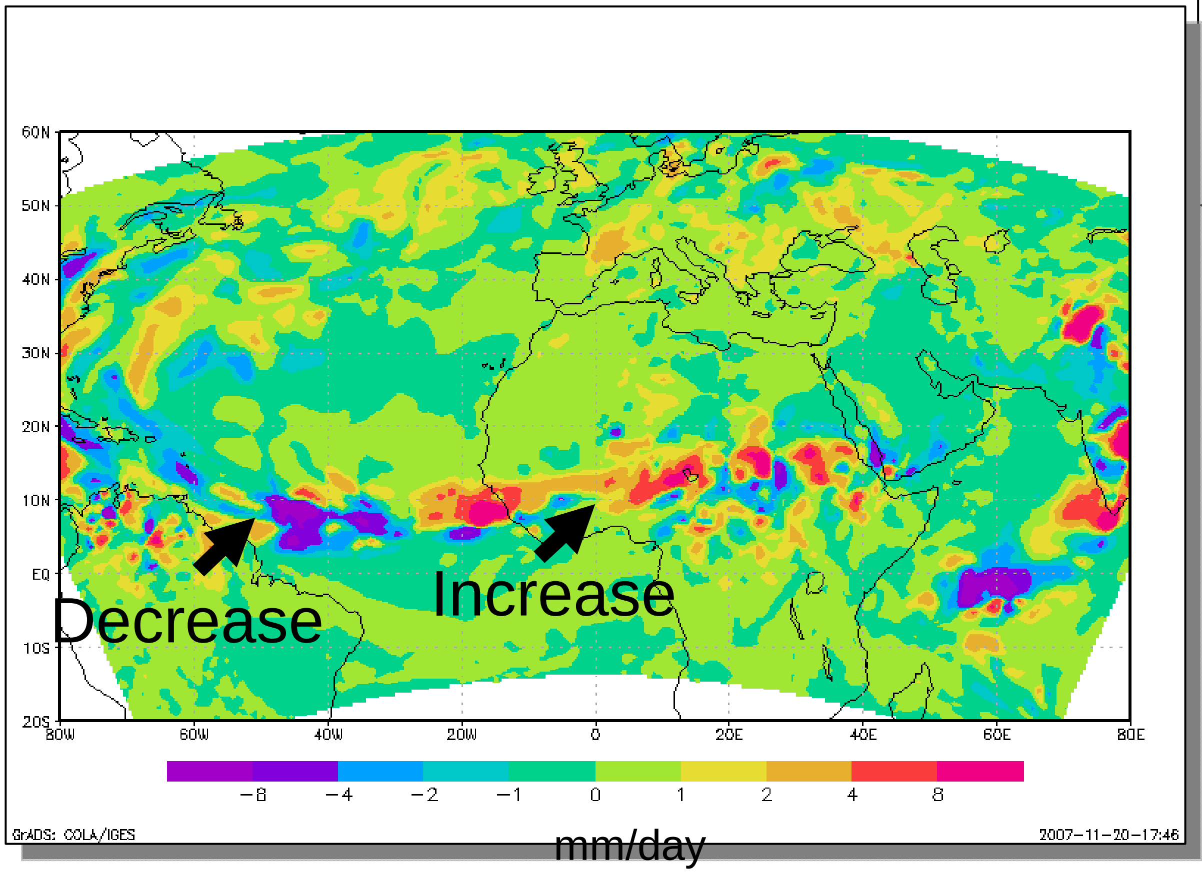
SST Change (K)



Domain size important for regional model

Small domain:
No sensitivity to SST





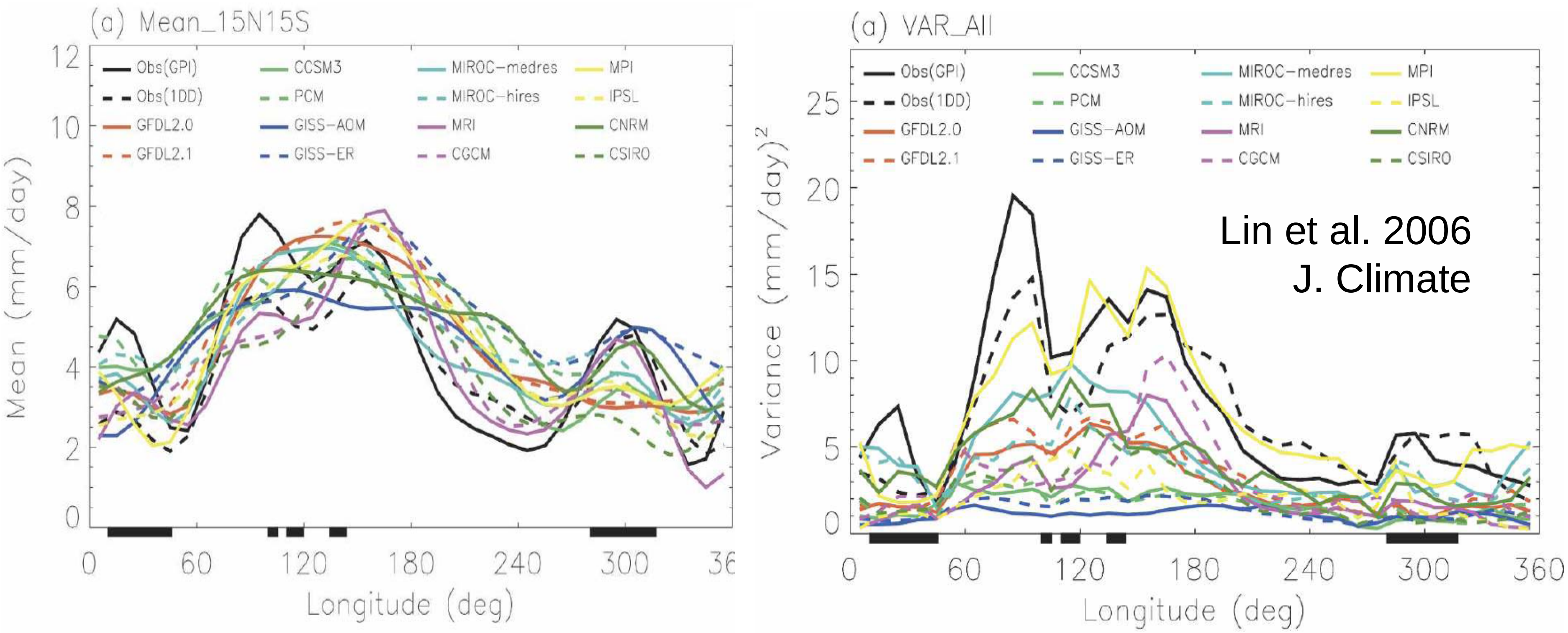
Large Domain:
increase in precip over Sahel as expected
(noisy as single season)

Why is this so?

- Net ascending motions (Convection) and latent heating in the RCM is constrained by
  - Radiative forcing WARM SST DOES NOT CHANGE
  - Convergence set by boundary conditions IDENTICAL IN EACH RUN

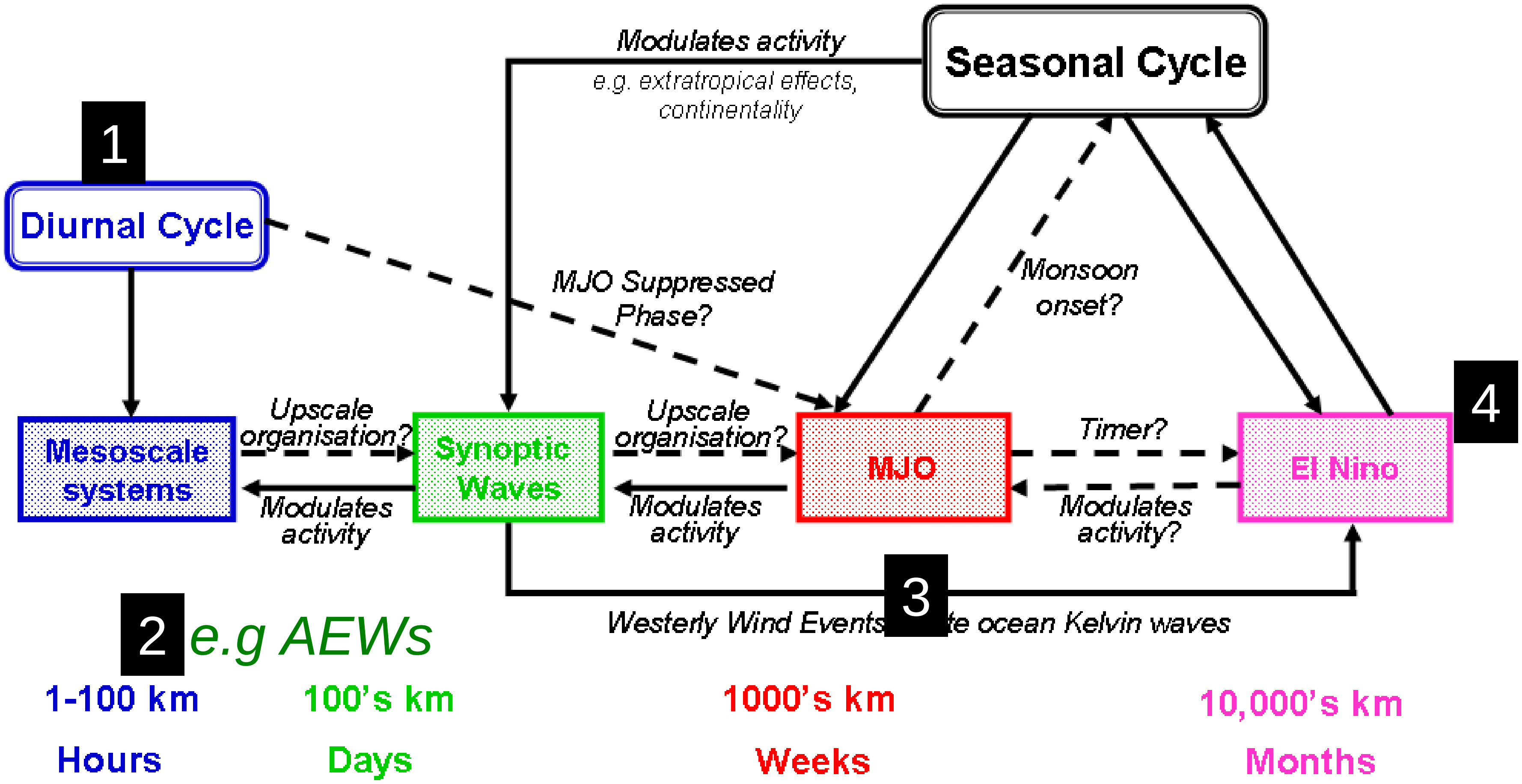
- Therefore: (large-scale) variability in GCMs is important, since it will also determine the variability of the climate simulation in the regional climate model

Tropical precipitation in 14 IPCC GCMs



- Much greater variation between models for precipitation variance
- All models underestimate precipitation variance compared to observations
- Variance includes many tropical “modes” across different time and space scales

Interactions between space and time scales of tropical convection: Linking THORPEX and WCRP



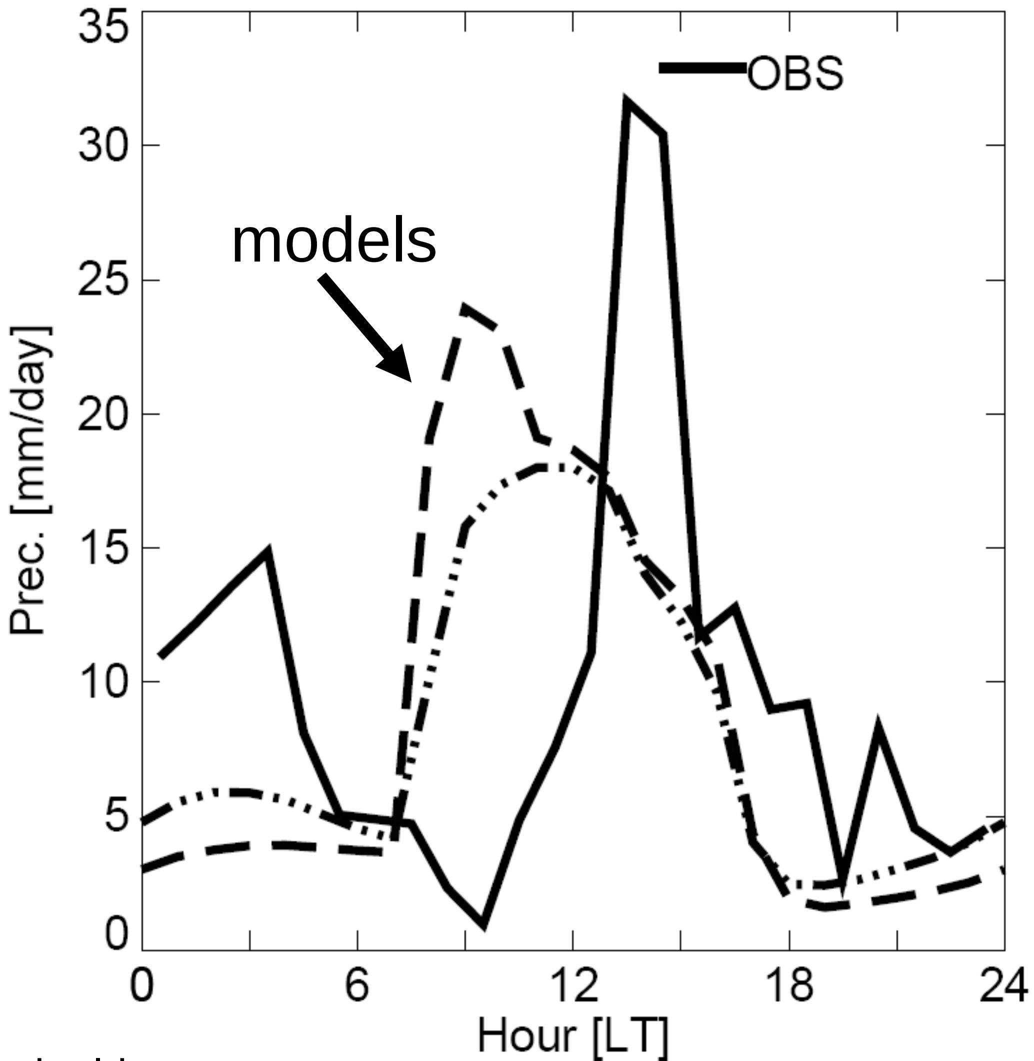
From THORPEX/WCRP Workshop on Organised Convection and the MJO

1. Diurnal and seasonal cycle

- Fundamental externally forced modes of the climate system.
- Represent largest variations in the climate system.
- Provide a basic test of the model physics.
- Changes in the amplitude and phase of the response of the climate system to these external forcings are one of the likely consequences (fingerprints?) of climate change.
- Also have significant impacts on the socio-economic effects of climate change.

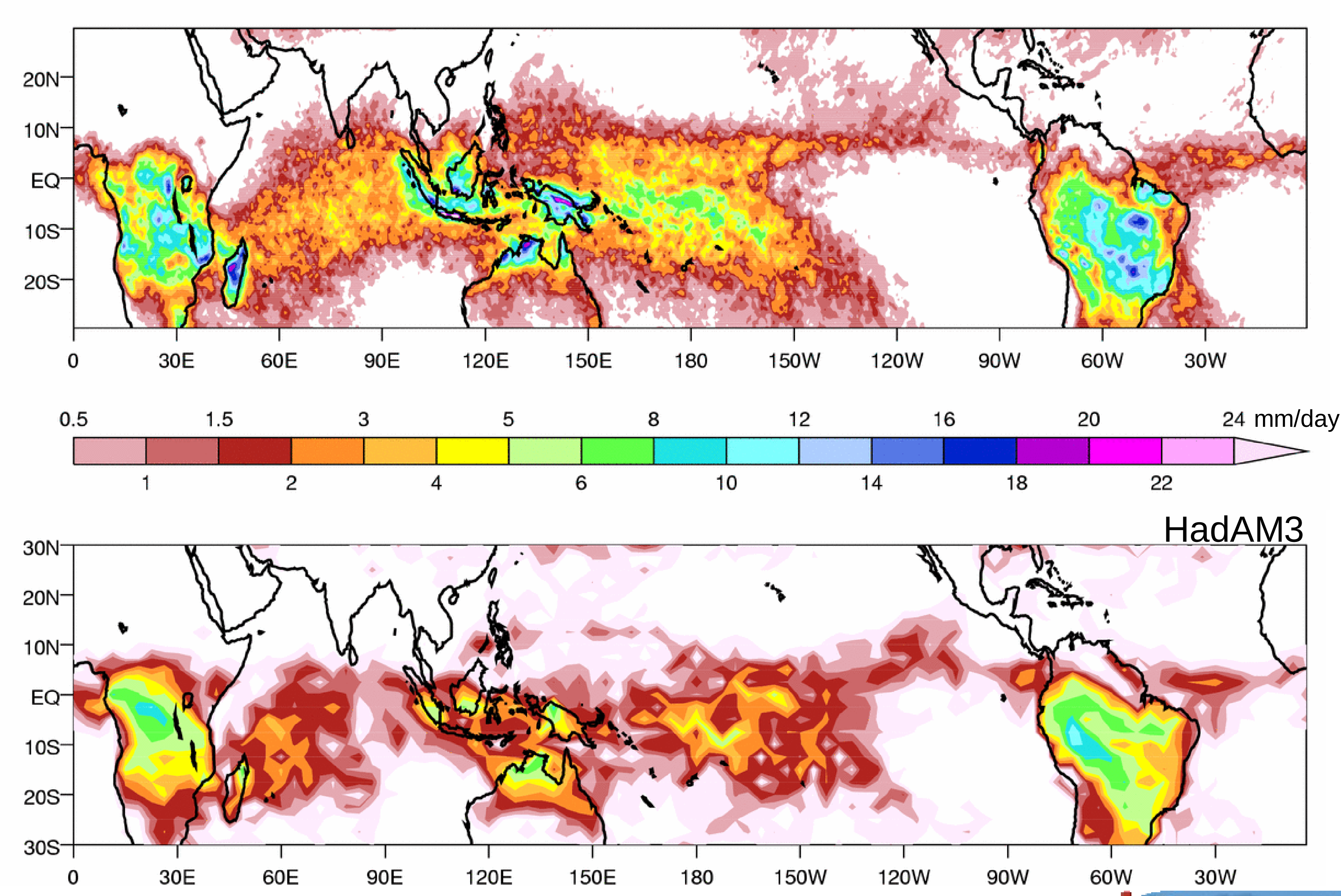
J. Slingo: “Should be (but isn’t!) a fundamental part of climate model evaluation”

Example: Two ECMWF forecast model versions compared to TRMM over LBA site Brazil



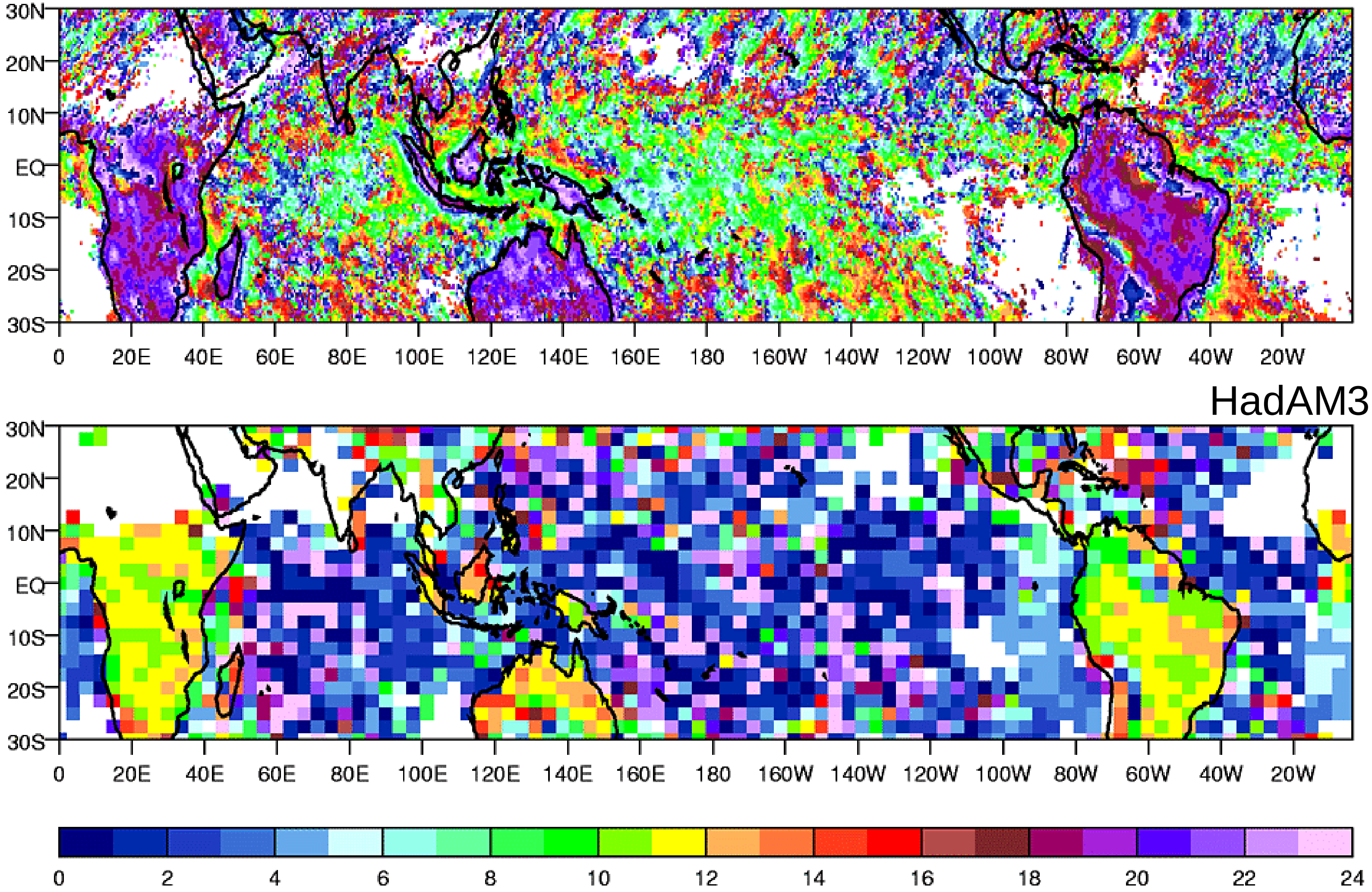
From P. Bechtold

Amplitude of diurnal harmonic in precipitation (cold clouds): DJF



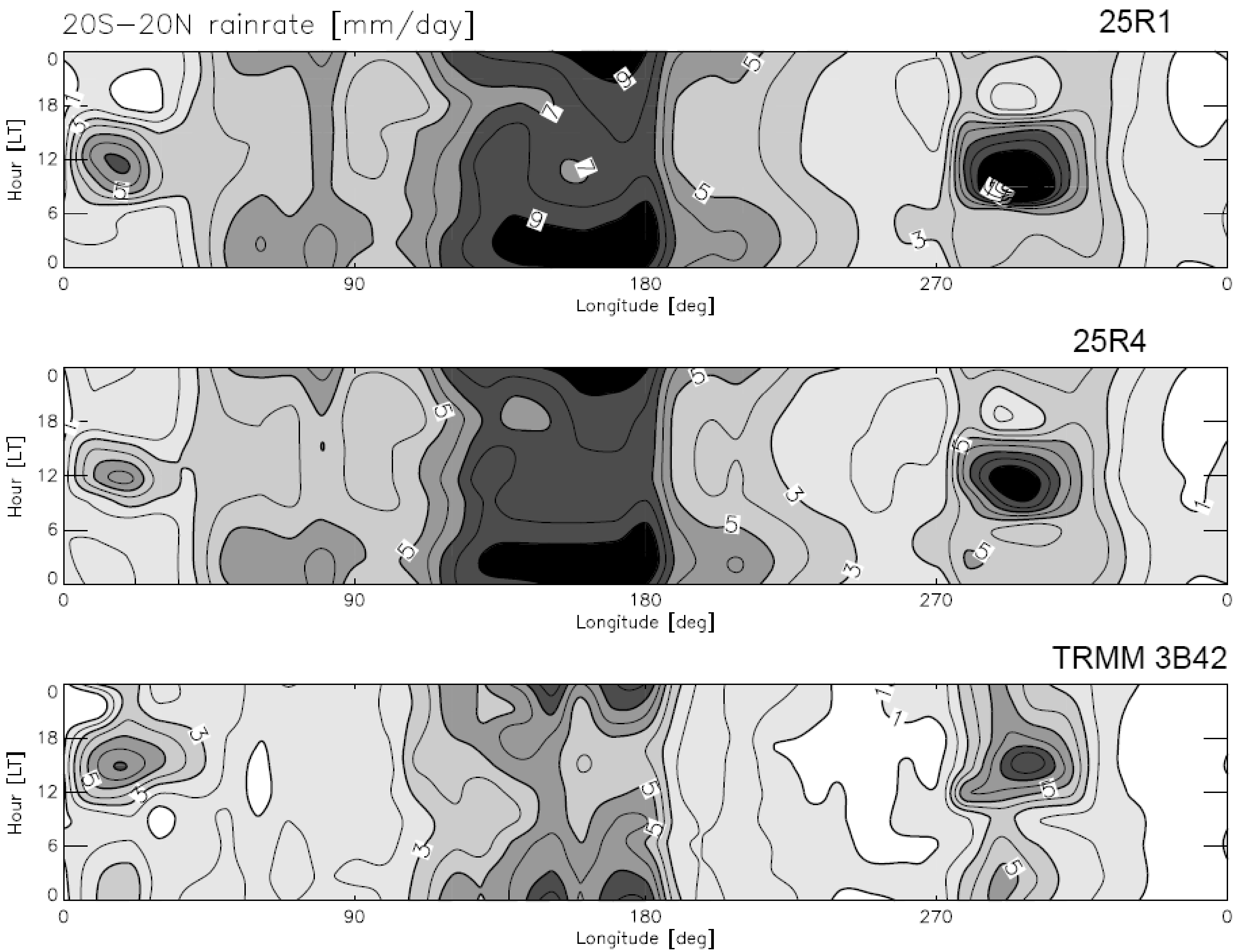
Ref: Yang and Slingo, 2001: *Monthly Weather Review*, **129**, 784-801

Phase of the diurnal harmonic in precipitation: DJF
Local time of maximum



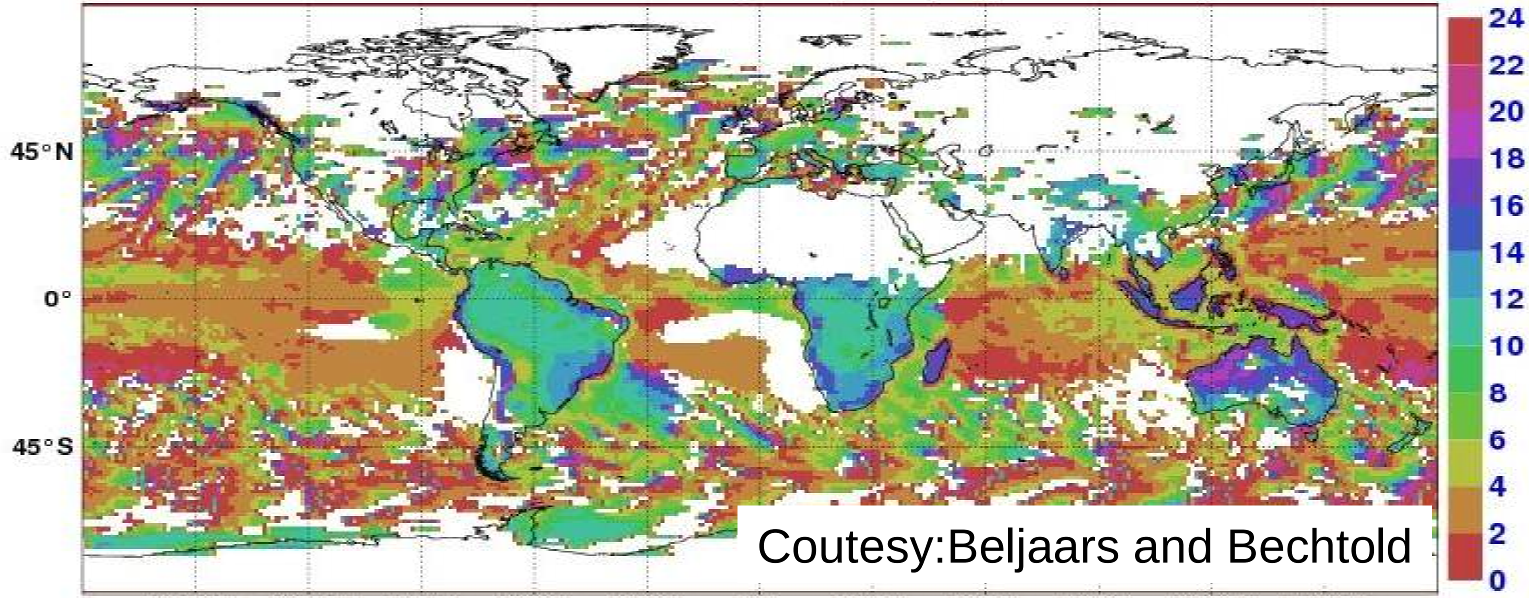
Note major errors in the timing of the maximum precipitation over land in the UM. This error is common to many models and indicates fundamental problems in representing the evolution of the boundary layer and the development of cumulus convection.

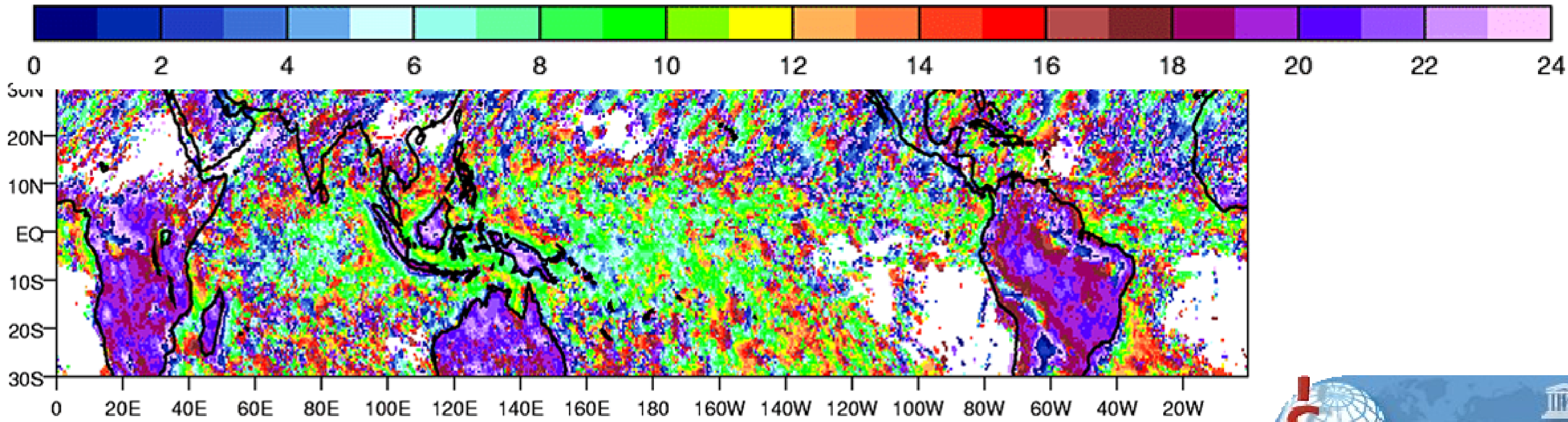
ECMWF forecast across Tropics: these are not easy problems to fix:



From P. Bechtold

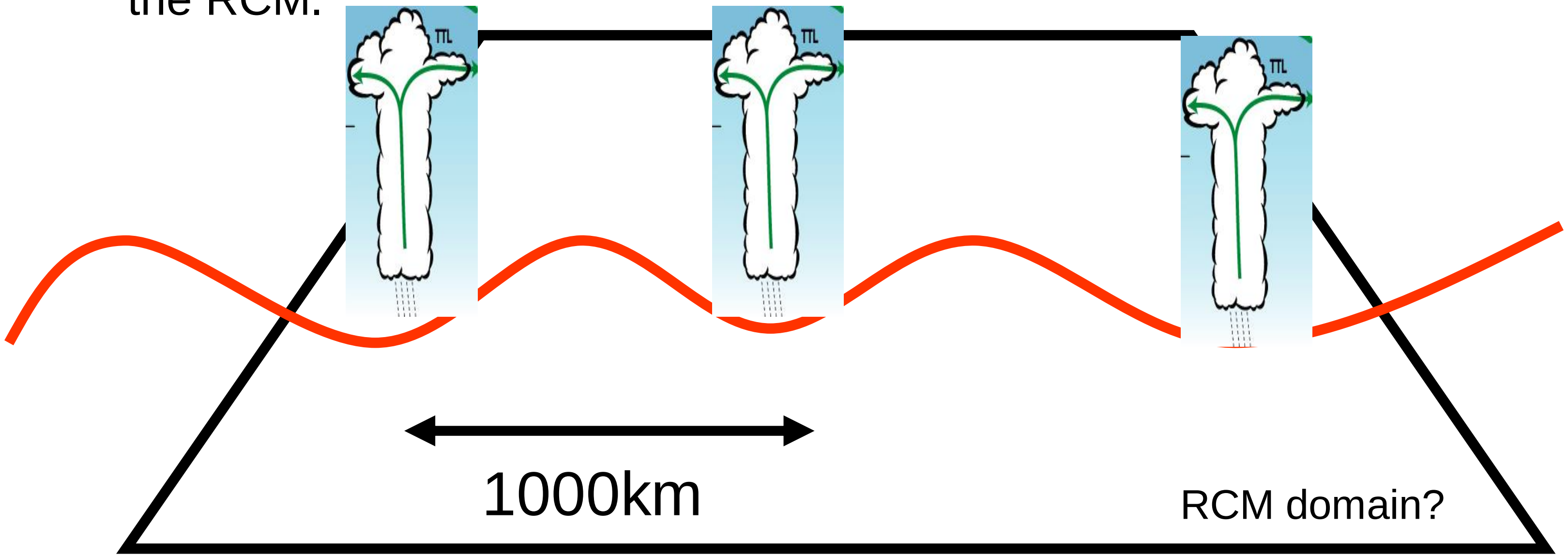
But progress has been made: CY32R3 operational from November 2007 (significant changes to convection scheme)





2. Mesoscale Systems: African Easterly Waves

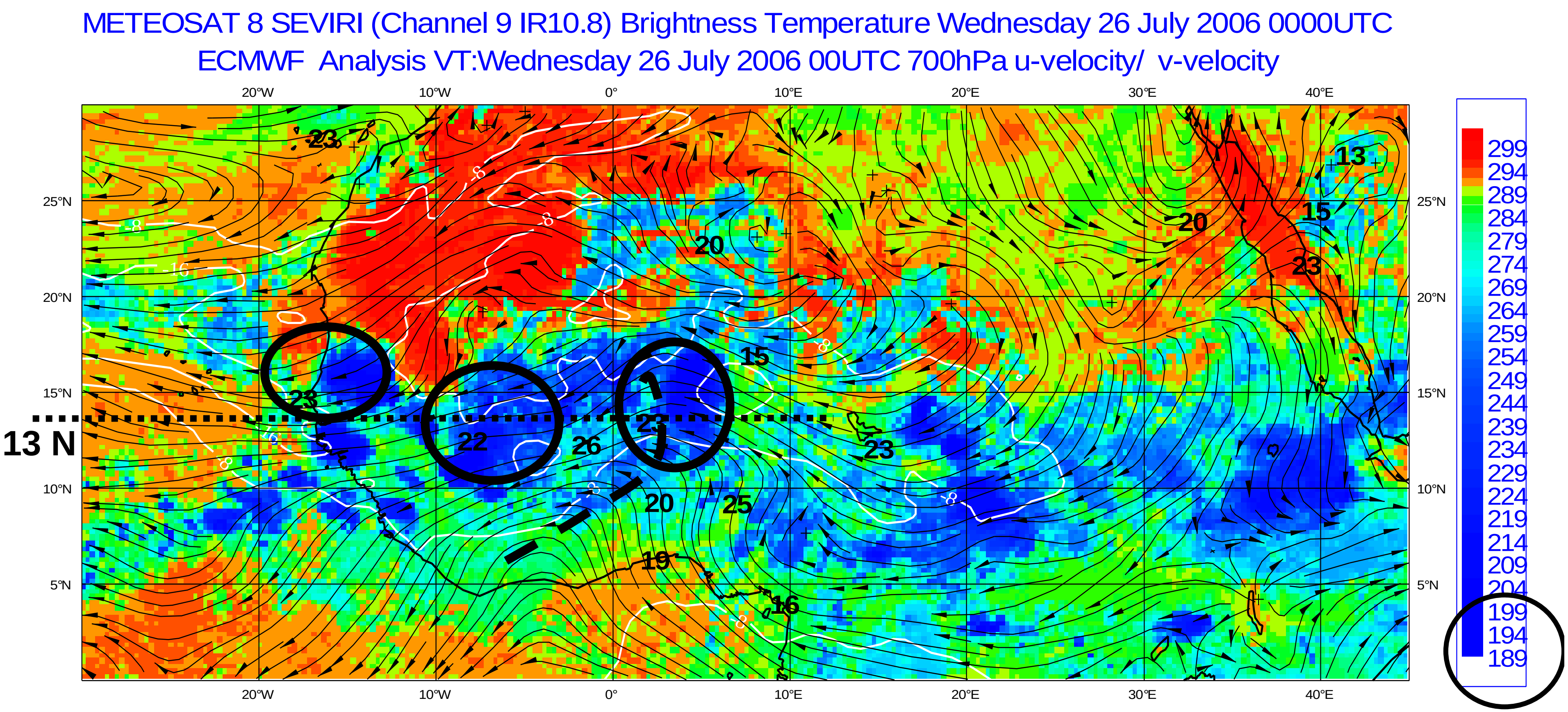
- Convection strongly coupled to O(1000km) African Easterly Waves – Most surface rainfall from organised systems in this region.
- Sub-domain for regional climate models? But again, recall that around 80% of the surface precipitation in Africa comes from organised systems, if they are lacking in the GCM, the forcing will be lacking for the RCM.



- How do global models do?

Brightness Temperature 26 July 2006 00 UTC

Meteosat Tb + 700 hPa steamfunction (T+00)

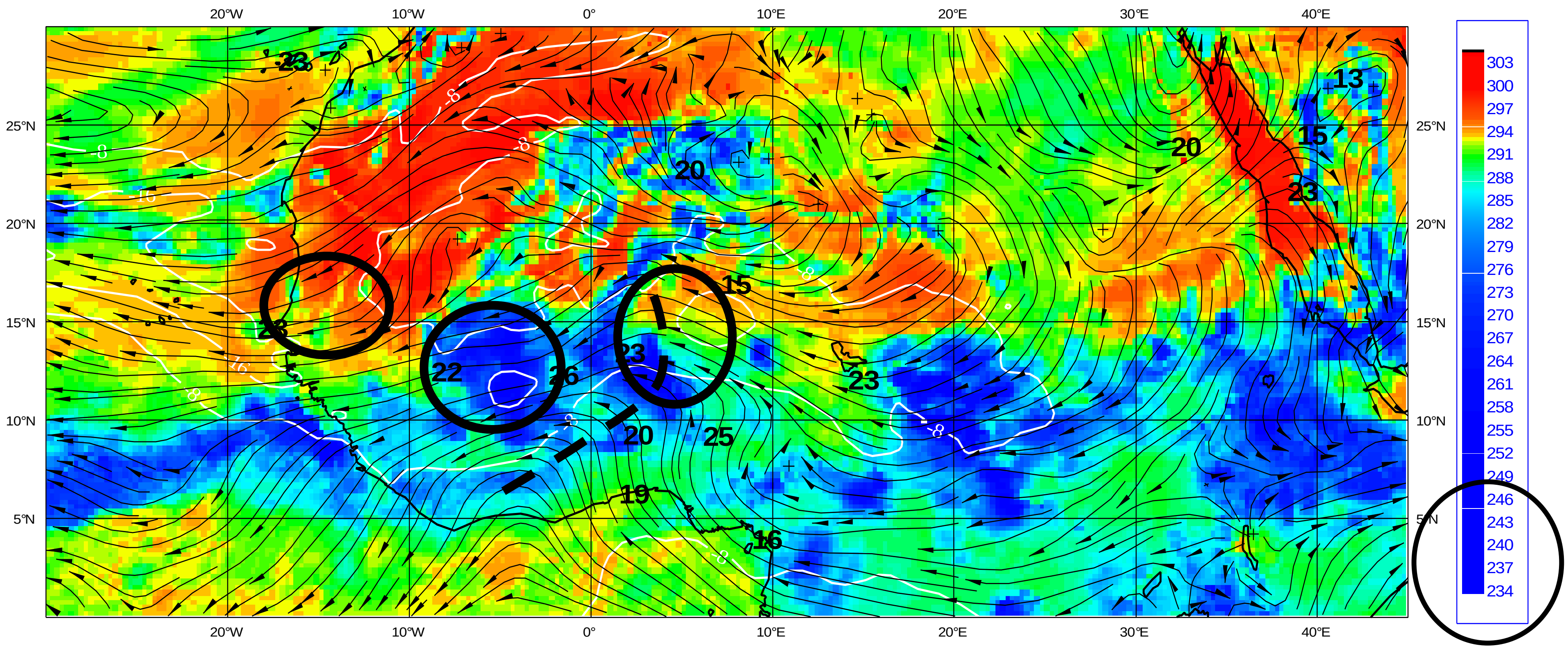


From Anna Agusti-Panareda

Brightness Temperature
26 July 2006 00 UTC

Simulated Tb (T+00) + 700 hPa steamfunction (T+00)

Wednesday 26 July 2006 00UTC ECMWF   t+0 VT:Wednesday 26 July 2006 00UTC
RTTOV generated METEOSAT 8 SEVIRI (Channel 9 IR10.8) Brightness Temperature (10 bit)

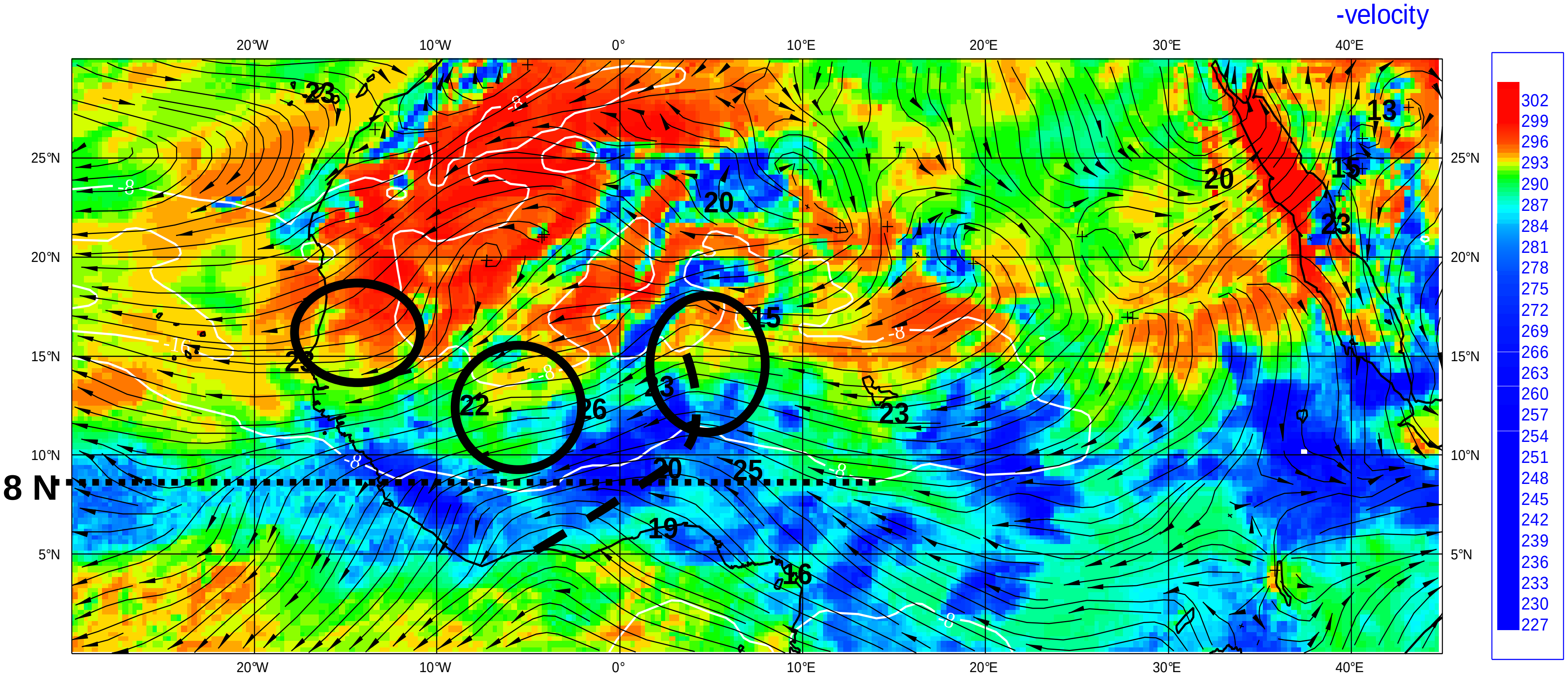


From Anna Agusti-Panareda

Brightness Temperature 26 July 2006 00 UTC

Simulated Tb (T+24) + 700 hPa steamfunction (T+24)

- Note (1) Wave activity reduced (2) precipitation band too far south (3) less predictability of less dynamically forced convection

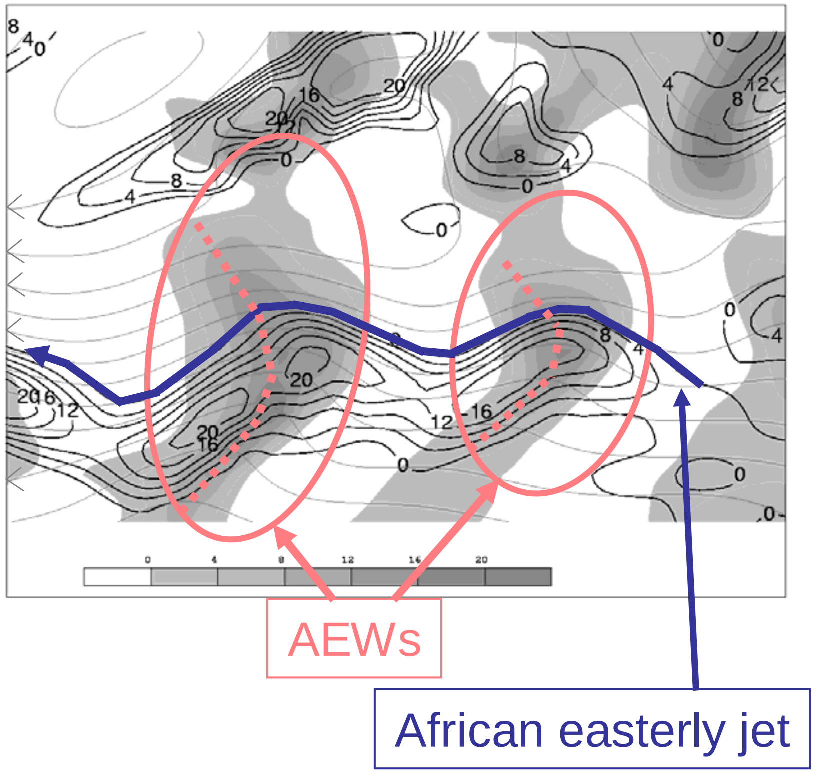


From Anna Agusti-Panareda

Diagnostics.

Following Berry, Thorncroft and Hewson (2006) are using curvature and shear vorticity at 700hPa as the primary diagnostics. As this partitioning helps to isolate AEWs:

Streamlines with Curvature (shaded) and shear vorticity:



Examine AEW activity during July, August and September 2007 over the African continent in operational models from four centres:

(i) UK Met Office.

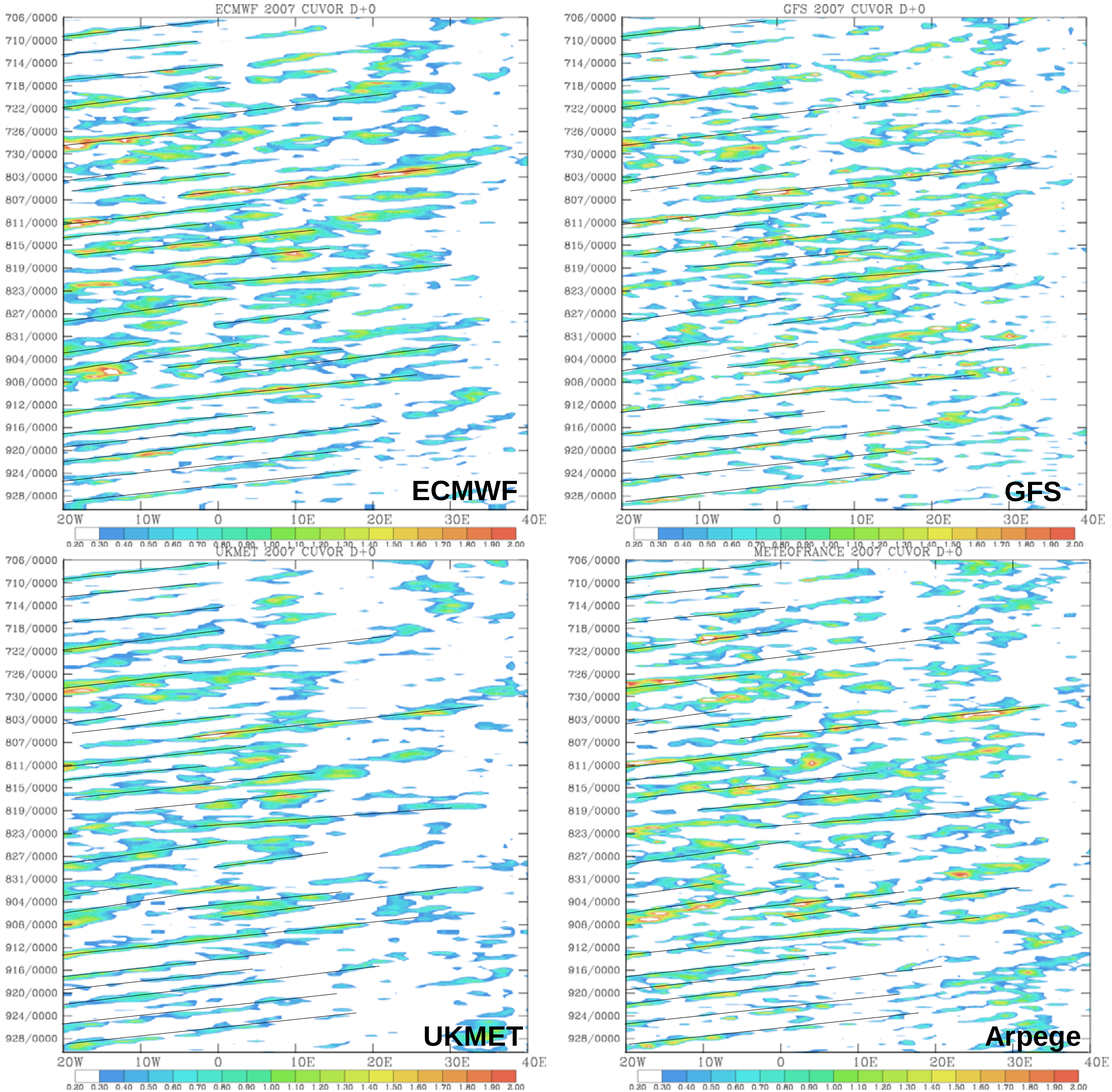
(ii) ECMWF.

(iii) NCEP (GFS)

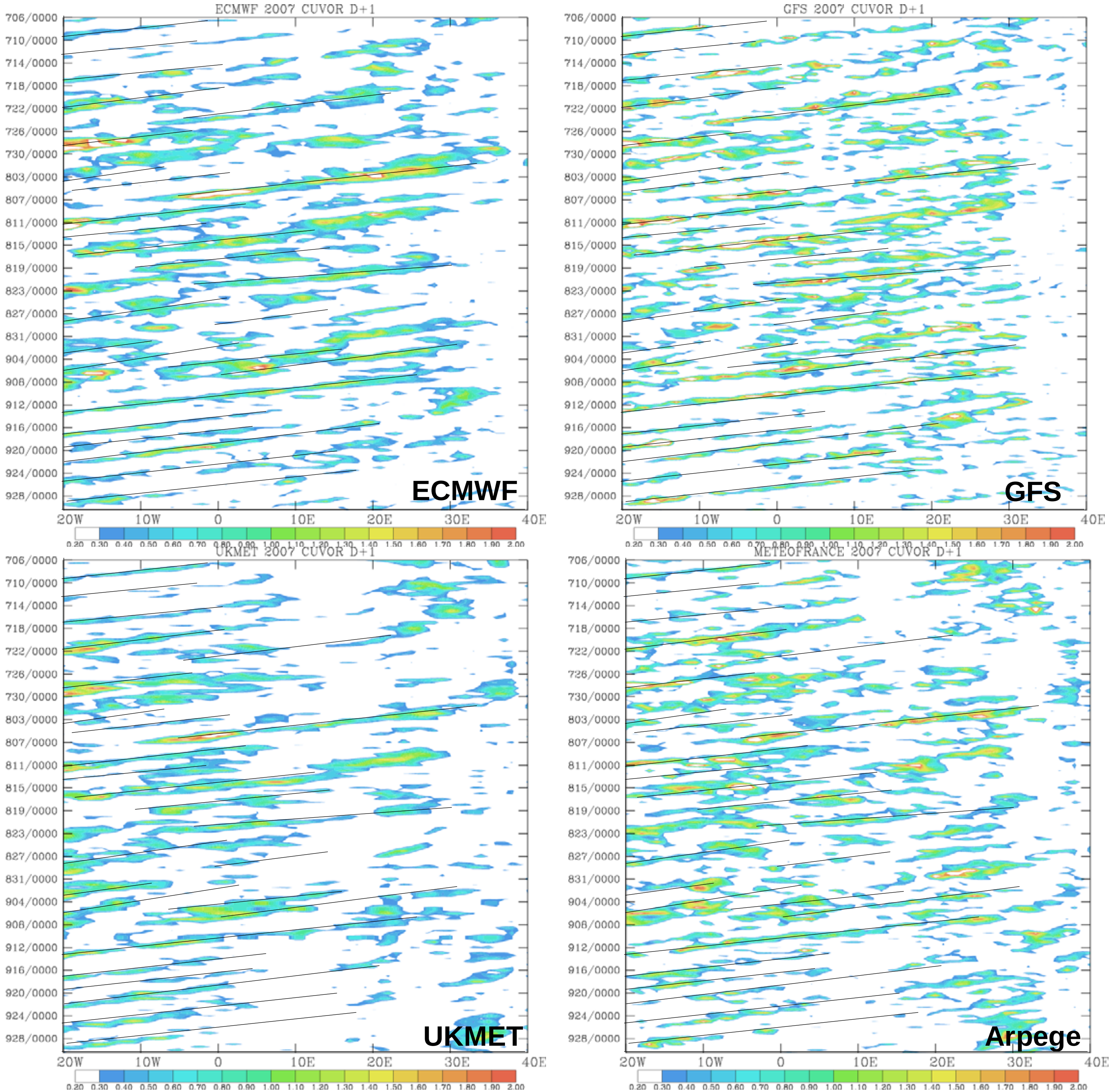
(iv) Meteo France (Arpege)

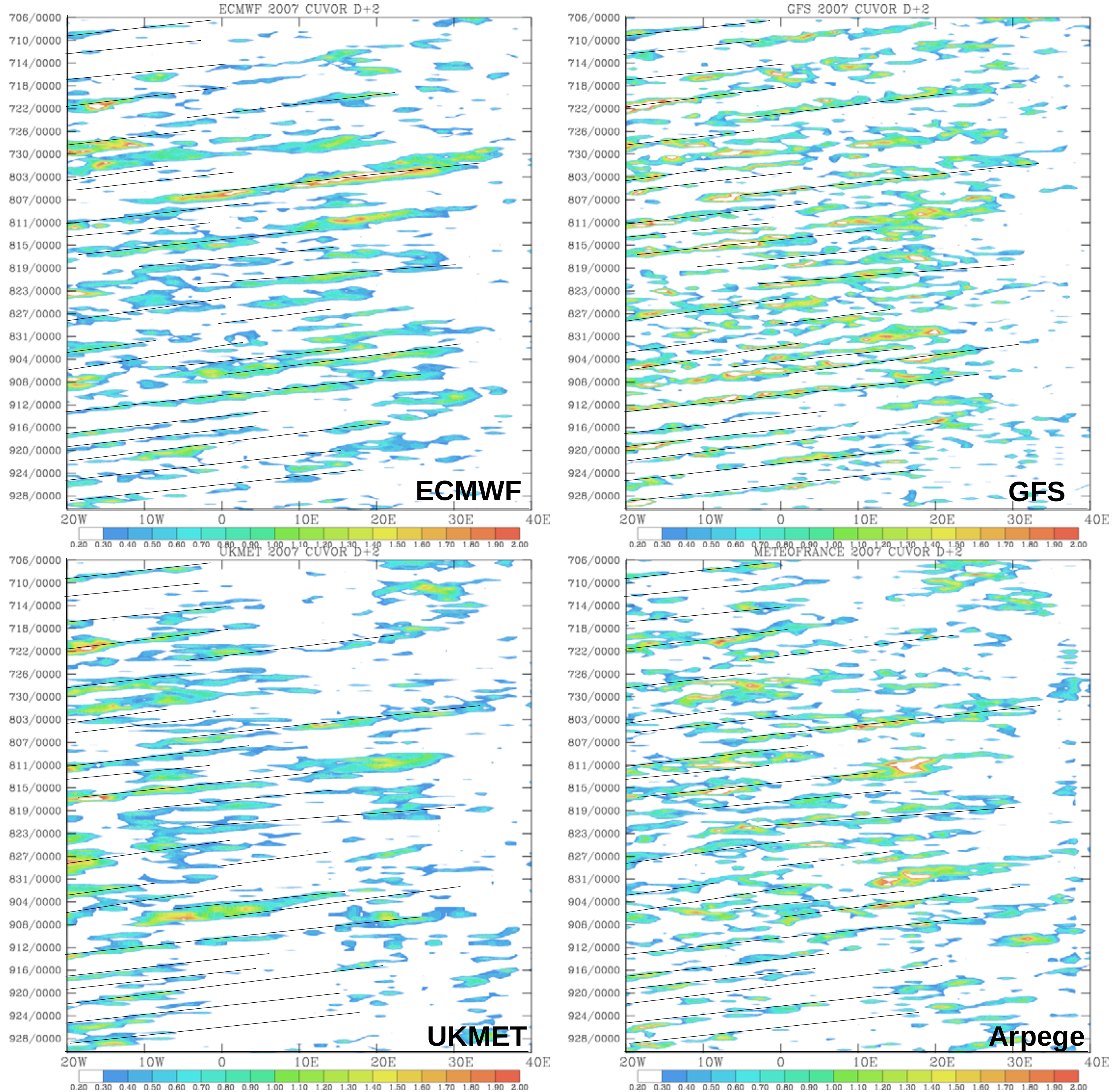
Work from Berry and Thorncroft

Analysis:
700hPa
curvature
vorticity.
Averaged
5-15N.



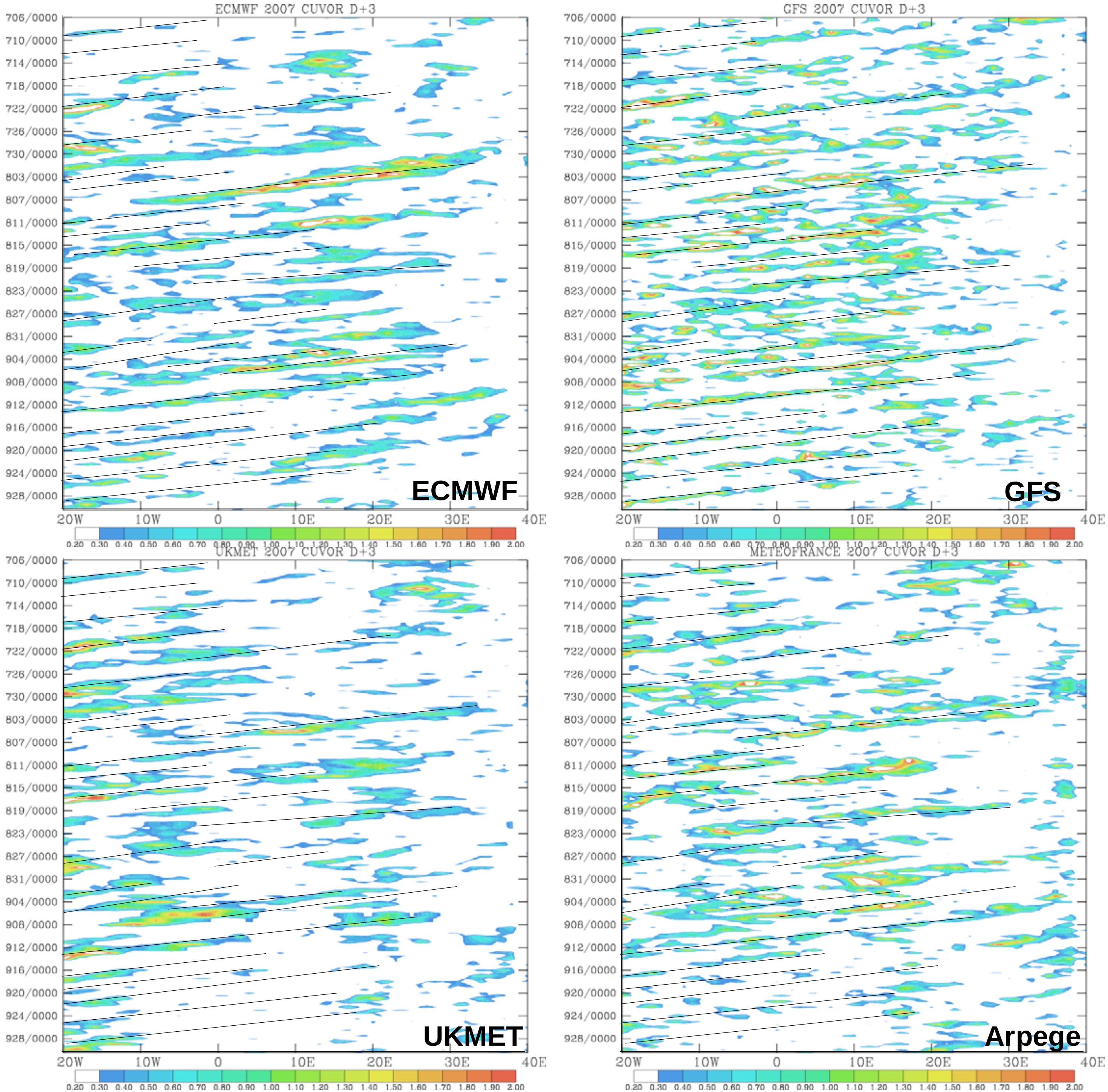
t+24hrs:
700hPa
curvature
vorticity.
Averaged
5-15N.



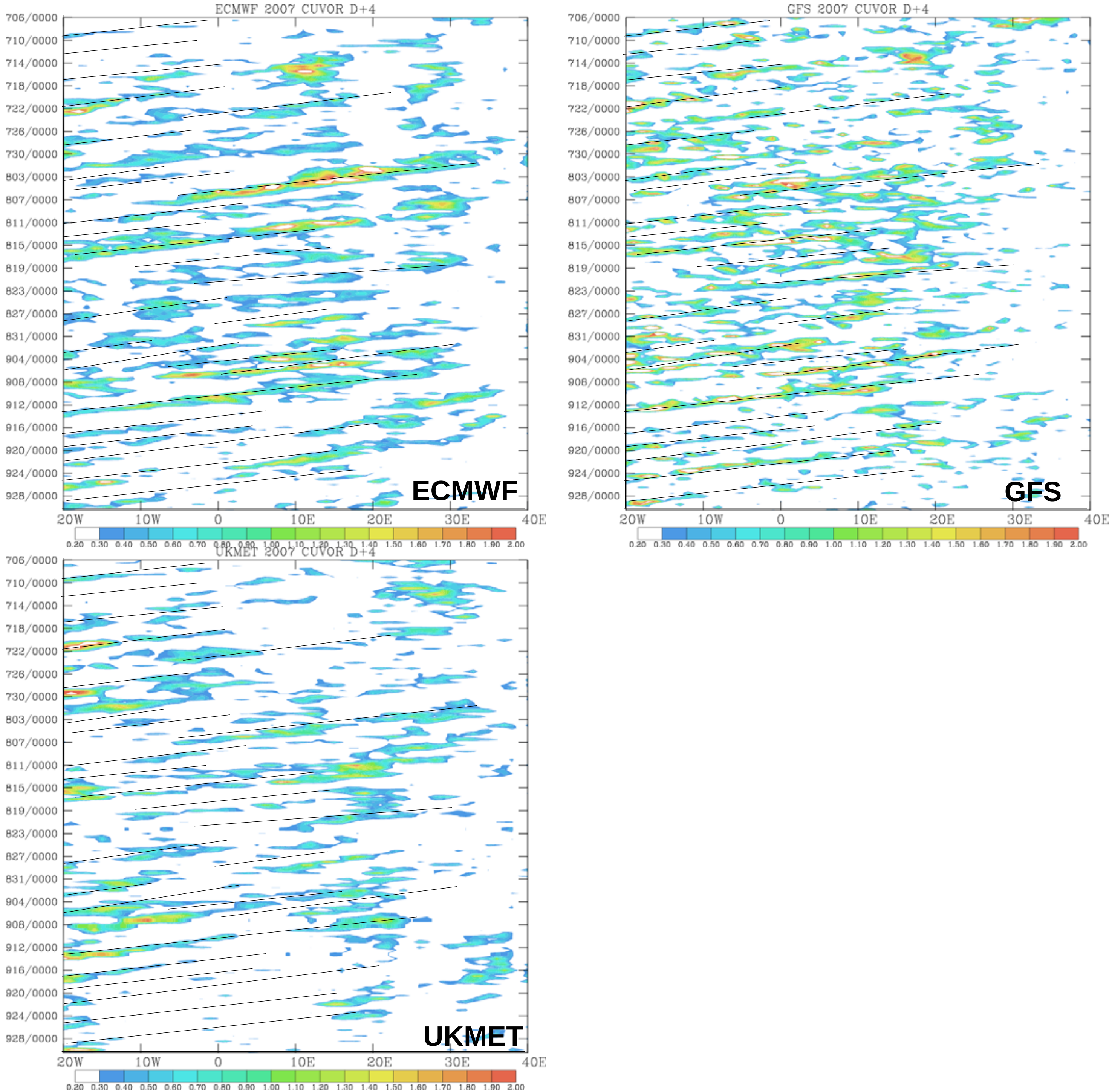


t+48hrs:
700hPa
curvature
vorticity.
Averaged
5-15N.

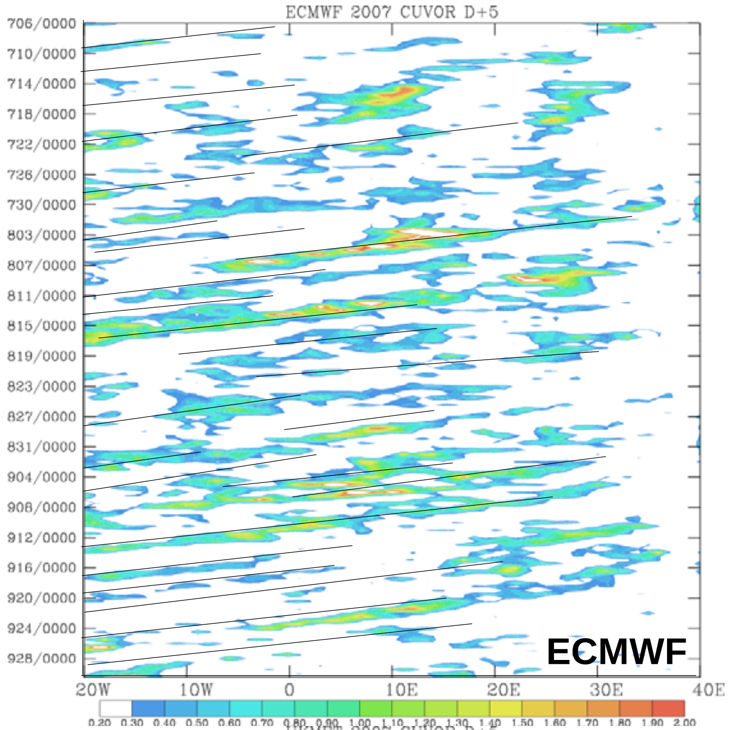
t+72hrs:
700hPa
curvature
vorticity.
Averaged
5-15N.

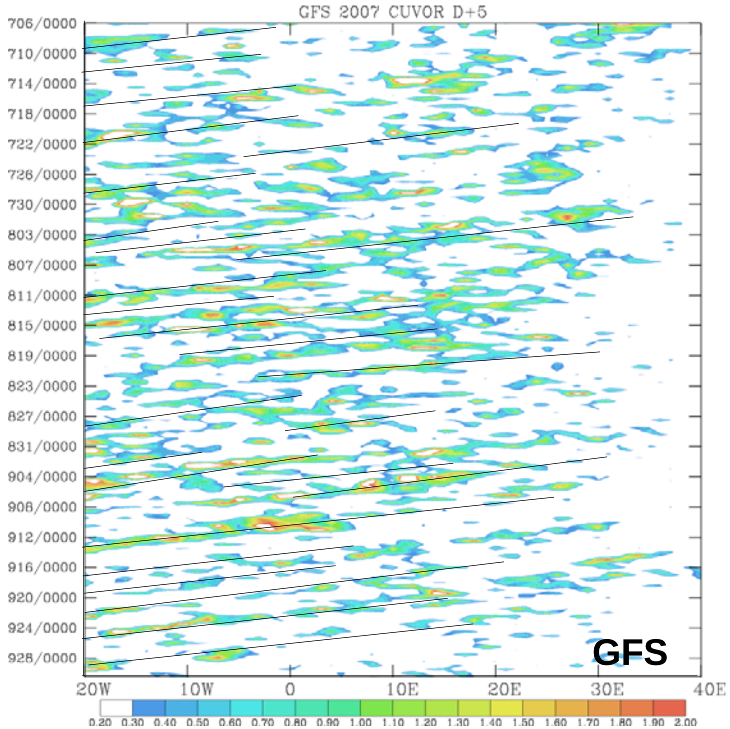


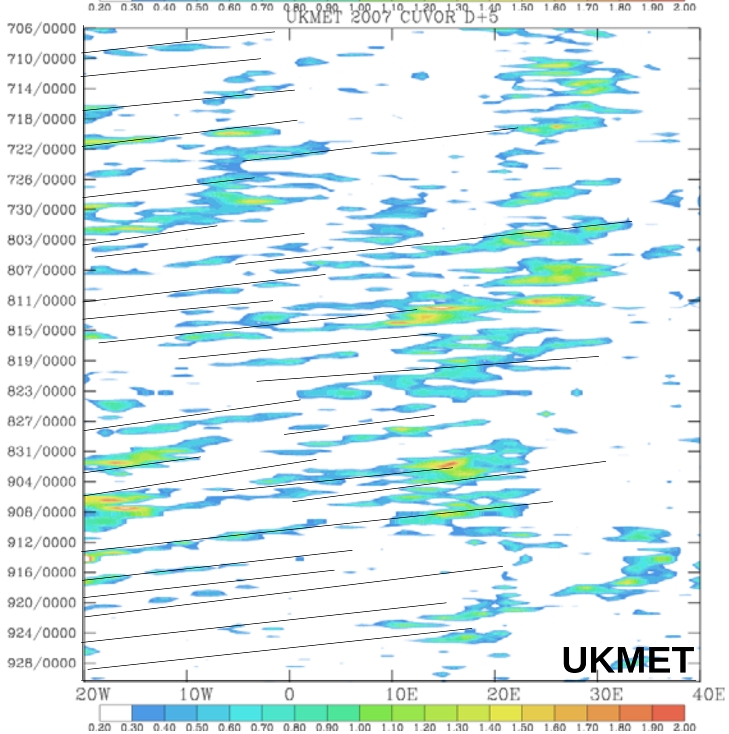
t+96hrs:
700hPa
curvature
vorticity.
Averaged
5-15N.



t+120hrs: 700hPa curvature vorticity. Averaged 5-15N.

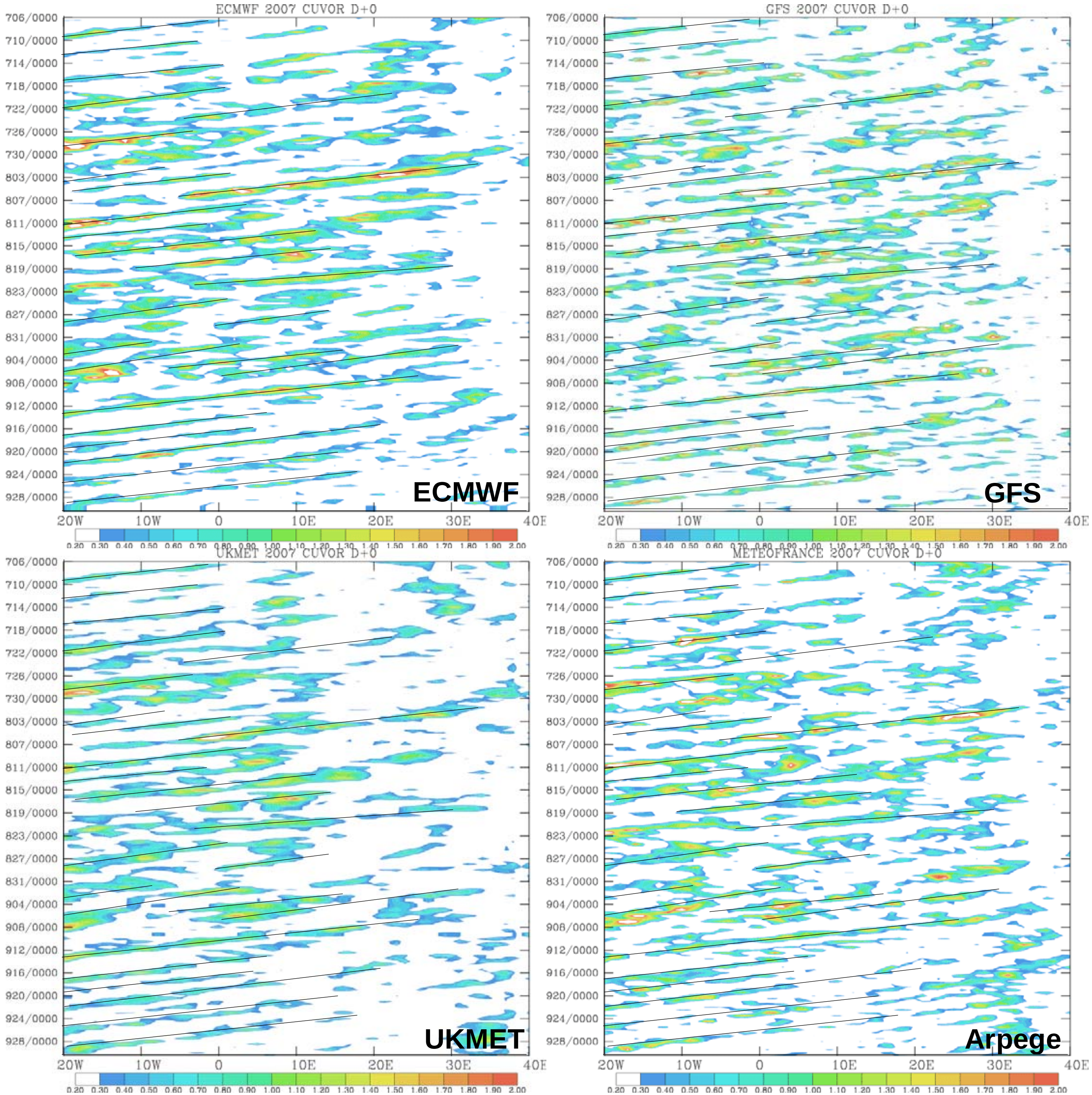






If AEW exists in analysis models can propagate feature

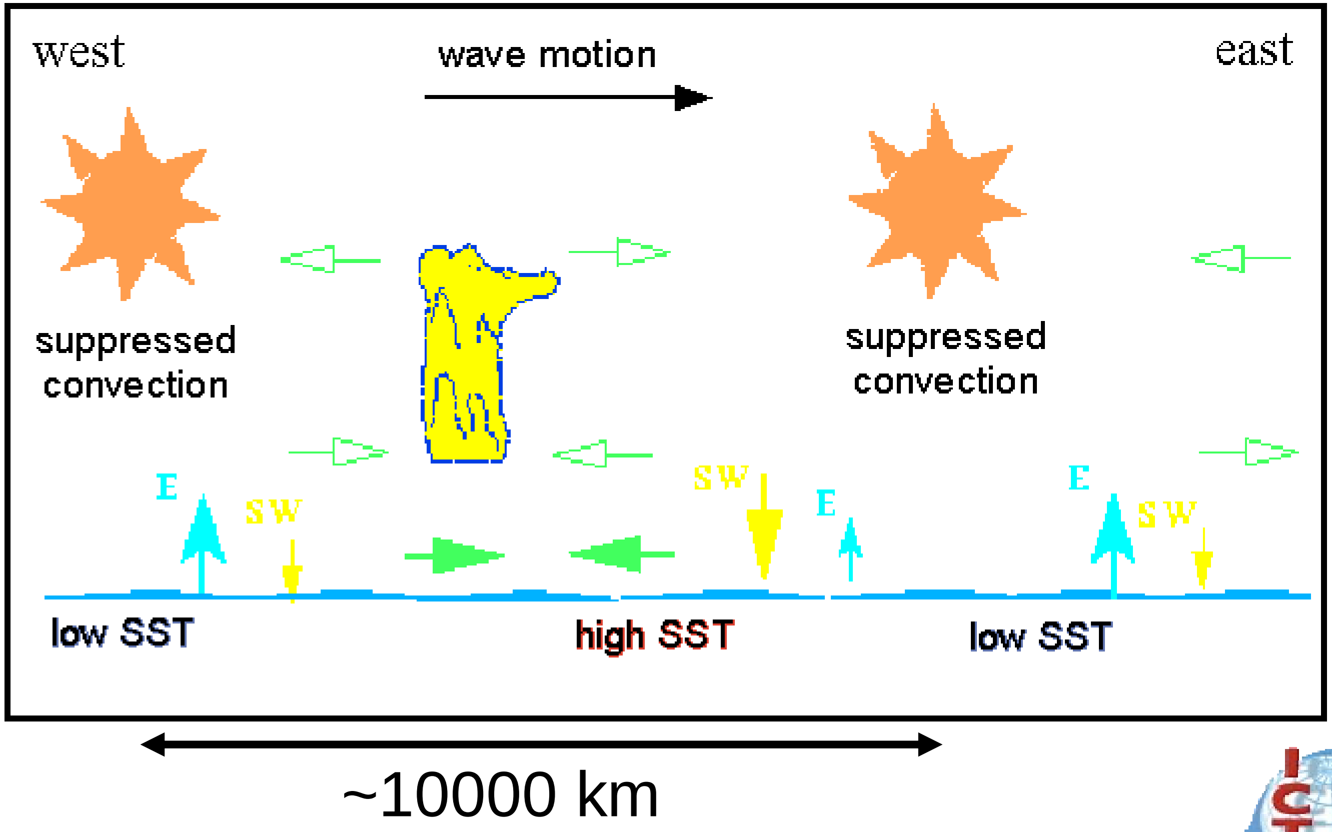
But initiation can be a problem



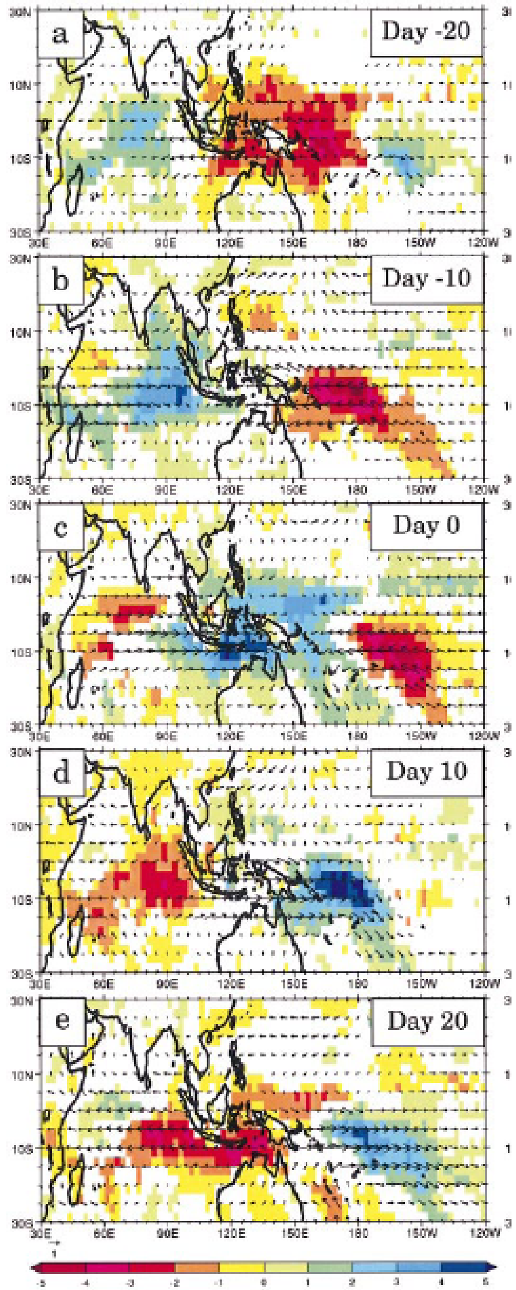
ECMWF 2007 CUVOR D+0
GFS 2007 CUVOR D+0
UKMET 2007 CUVOR D+0
METEOFRANCE 2007 CUVOR D+0
ECMWF
GFS
UKMET
Arpege
706/0000 710/0000 714/0000 718/0000 722/0000 726/0000 730/0000 803/0000 807/0000 811/0000 815/0000 819/0000 823/0000 827/0000 831/0000 904/0000 908/0000 912/0000 916/0000 920/0000 924/0000 928/0000
20W 10W 0 10E 20E 30E 40E
0.20 0.30 0.40 0.50 0.60 0.70 0.80 0.90 1.00 1.10 1.20 1.30 1.40 1.50 1.60 1.70 1.80 1.90 2.00

3. Madden-Julian Oscillation (MJO)

- Wave number 1 Convectively-coupled Eastward propagating (40-60 days) large-scale oscillation in the tropics



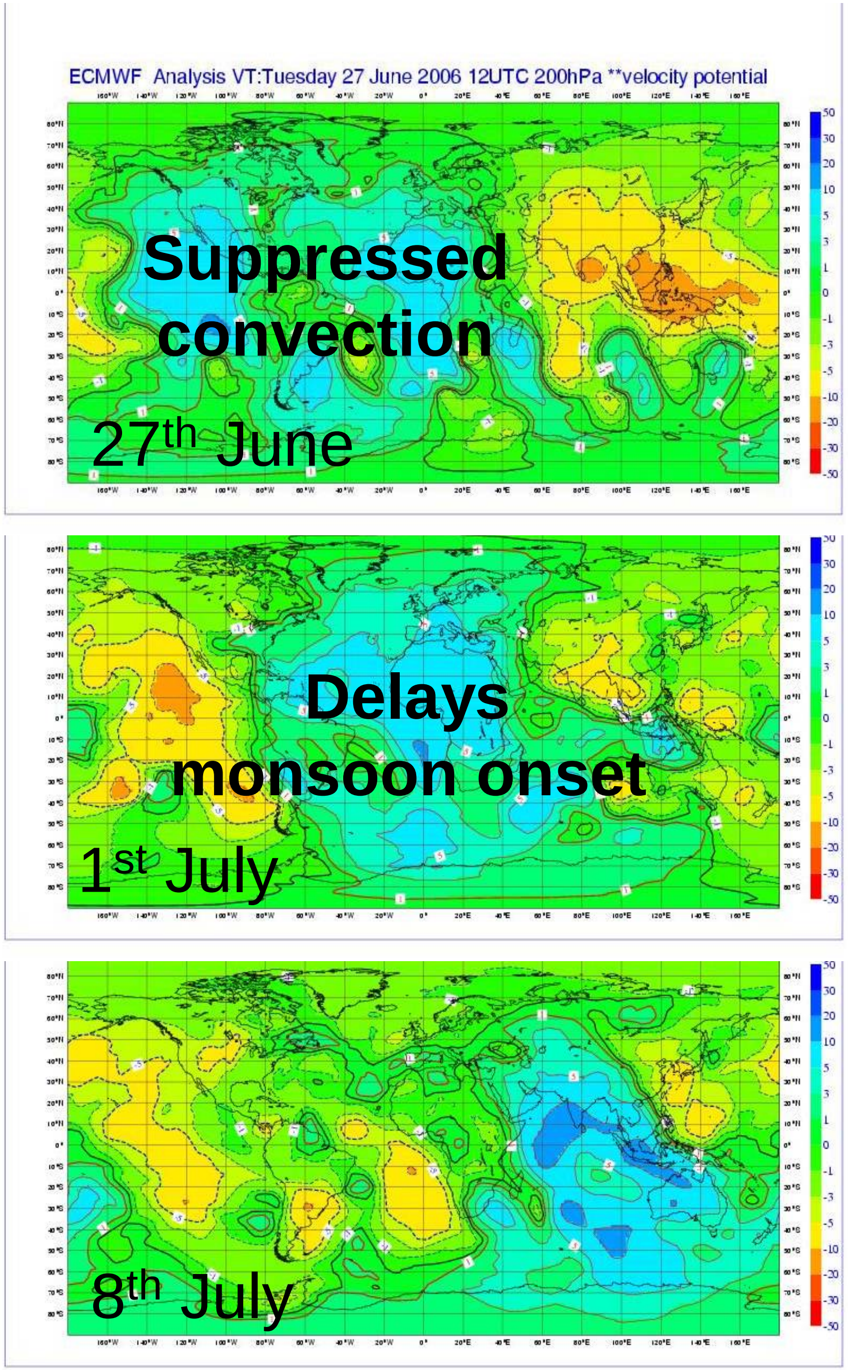
wheeler



MJO

- MJO strongly convectively coupled in Western Pacific
- Slower propagation speed
- Signal propagates faster in Eastern Pacific to Africa

Linear regression of 20-100d CMAP rainfall with PC1 of MJO
from Sperber 2003



ECMWF Analysis of the 200 hPa Velocity potential Anomaly

Large-scale wave-number 1 pattern associated with an MJO event

Using this, Andre Kamga of ACMAD in Niamey (correctly) predicted a late monsoon onset in 2006

Symmetric space-time spectra of precip in AR4 models

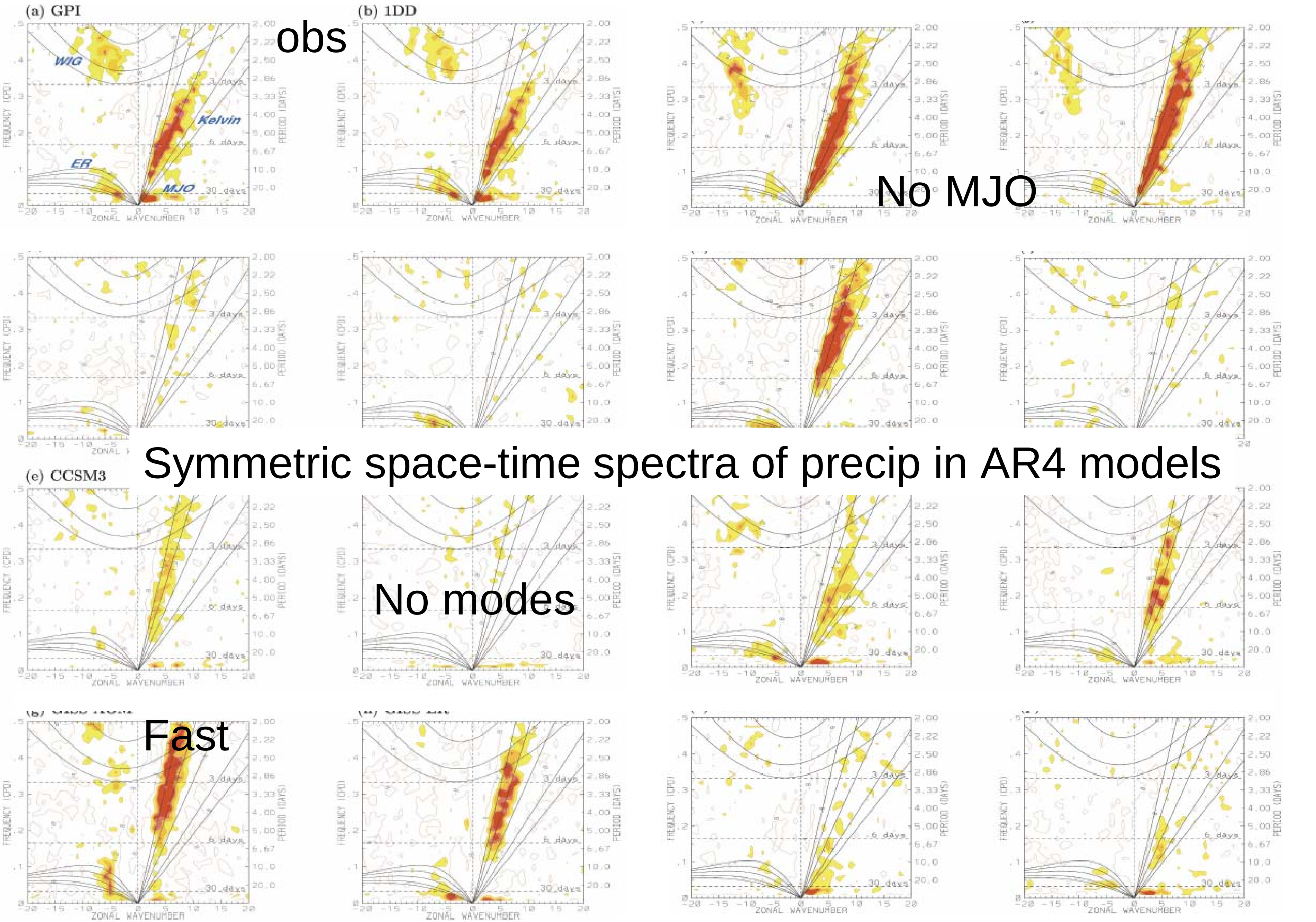


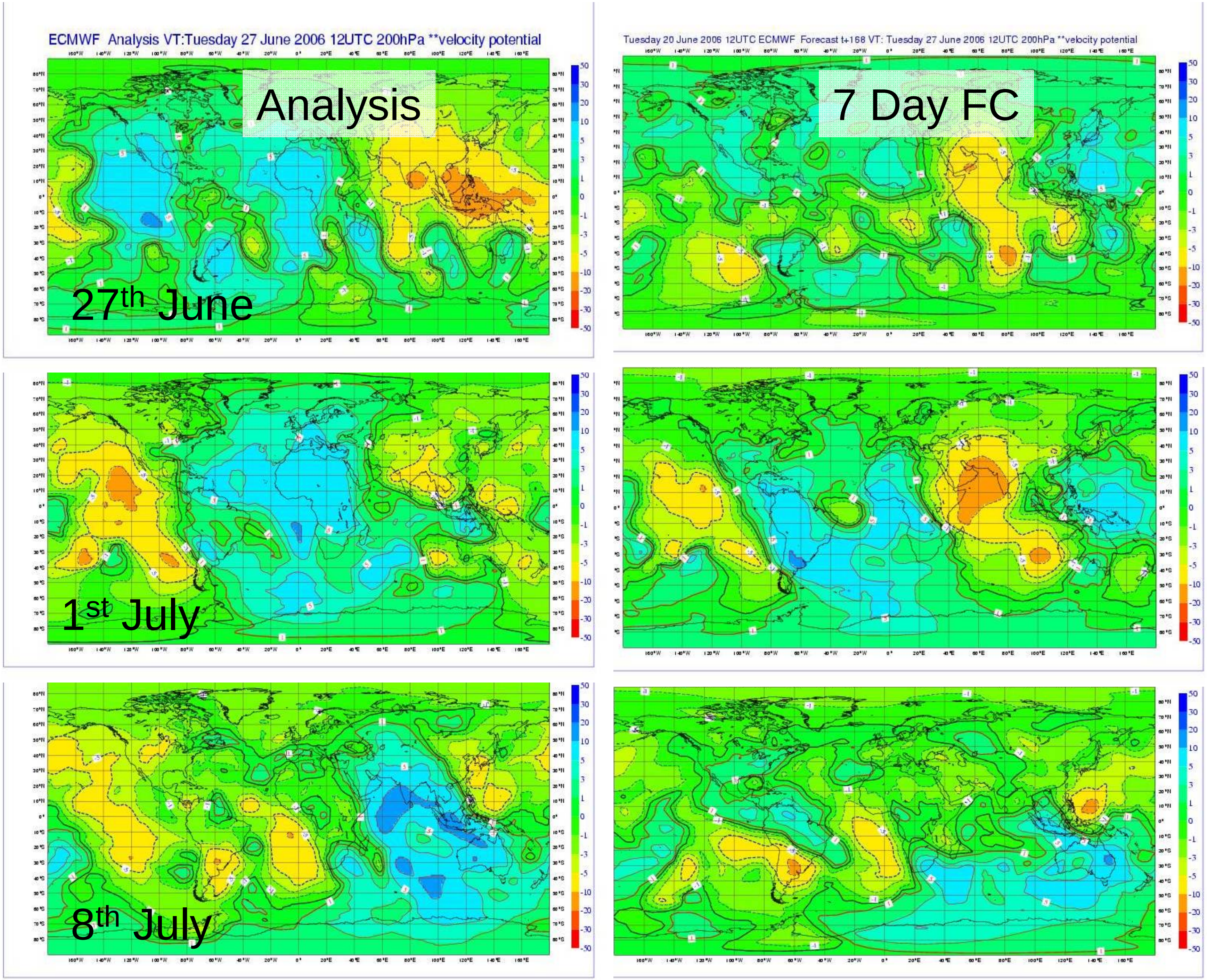
FIG. 6. Space–time spectrum of the 15°N–15°S symmetric component of precipitation divided by the background spectrum. Superimposed are the dispersion curves of the odd meridional mode numbered equatorial waves for the five equivalent depths of 8, 12, 25, 50, and 90 m. Frequency spectral width is 1/128 cpd.

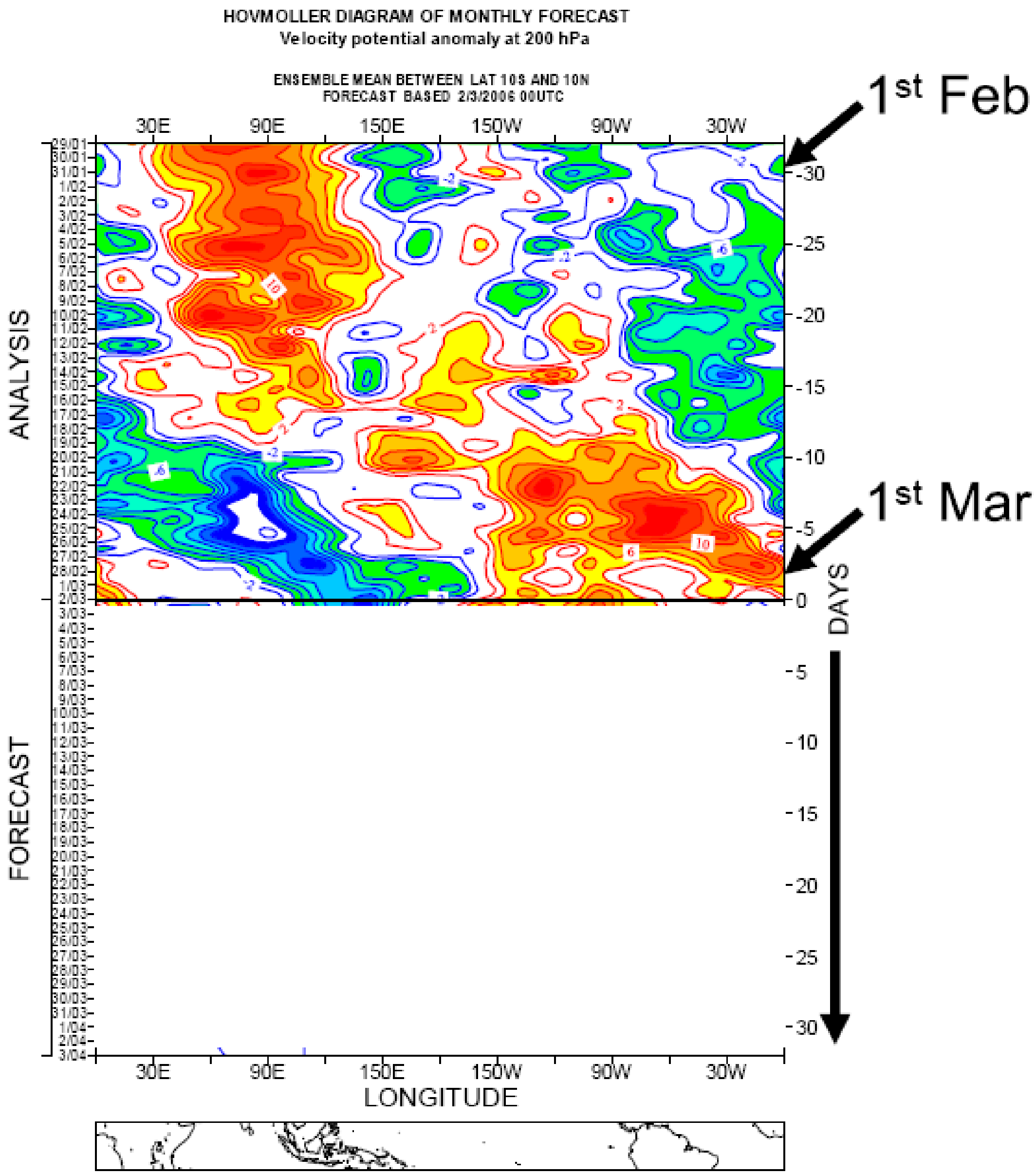
Lin et al. 2006

FIG. 6. (*Continued*)

MJO in global models

- Global models have notorious difficulty in representing the MJO
- Lack of understanding concerning the convective coupling mechanism: SSTs feedbacks, cloud-radiative feedbacks, water vapour feedbacks…
- No “magic bullet” (convection scheme, coupled ocean…) has yet been documented for MJO
- How does the ECMWF forecast do?


ECMWF Analysis VT:Tuesday 27 June 2006 12UTC 200hPa **velocity potential
Analysis
27th June
Tuesday 20 June 2006 12UTC ECMWF Forecast t+168 VT: Tuesday 27 June 2006 12UTC 200hPa **velocity potential
7 Day FC
1st July
8th July

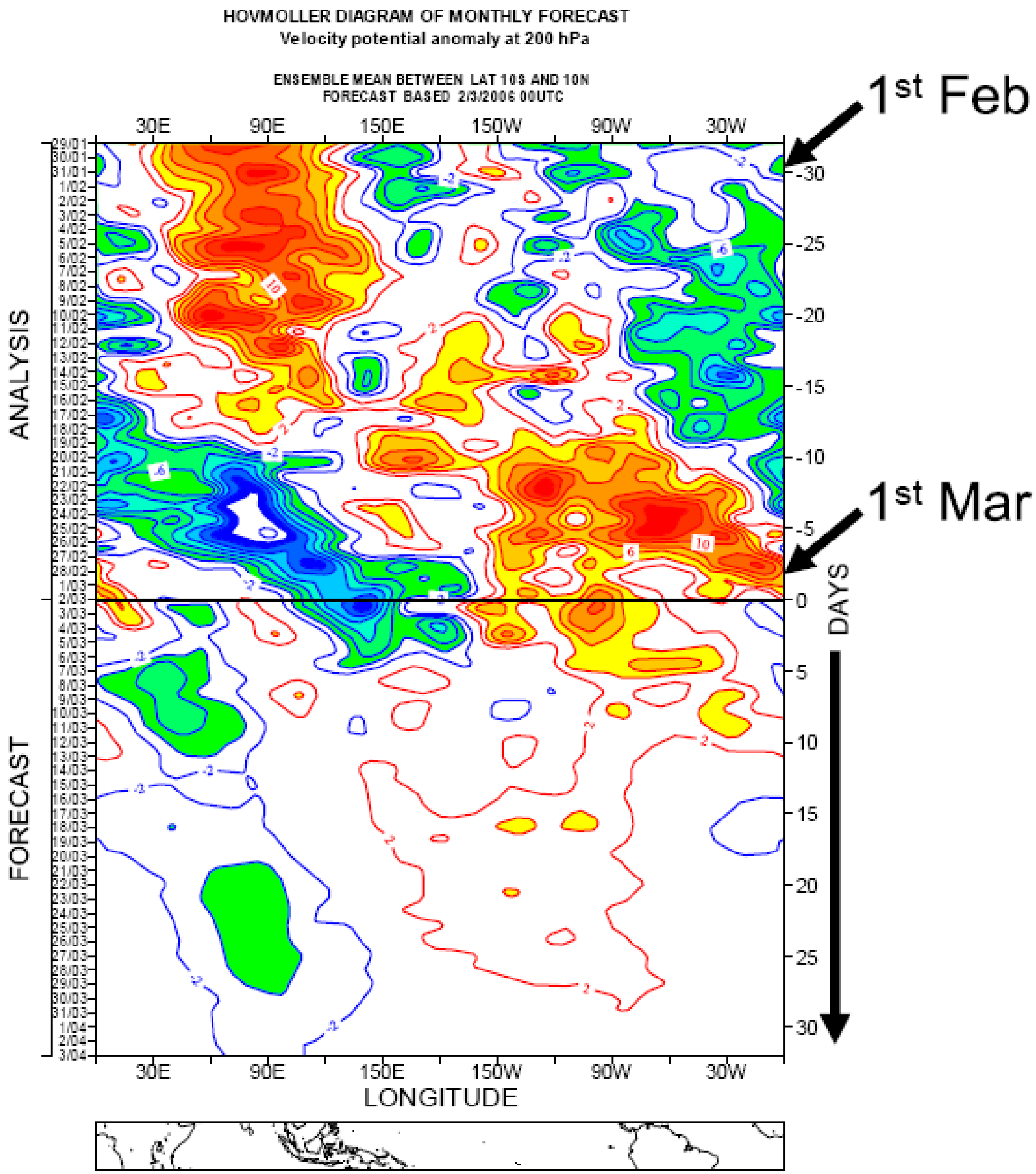


Typical MJO forecast at ECMWF

200hPa Velocity Potential Anomalies

February – March 2006

A typical MJO forecast from the ECMWF monthly forecast system in 2006



Typical MJO forecast at ECMWF

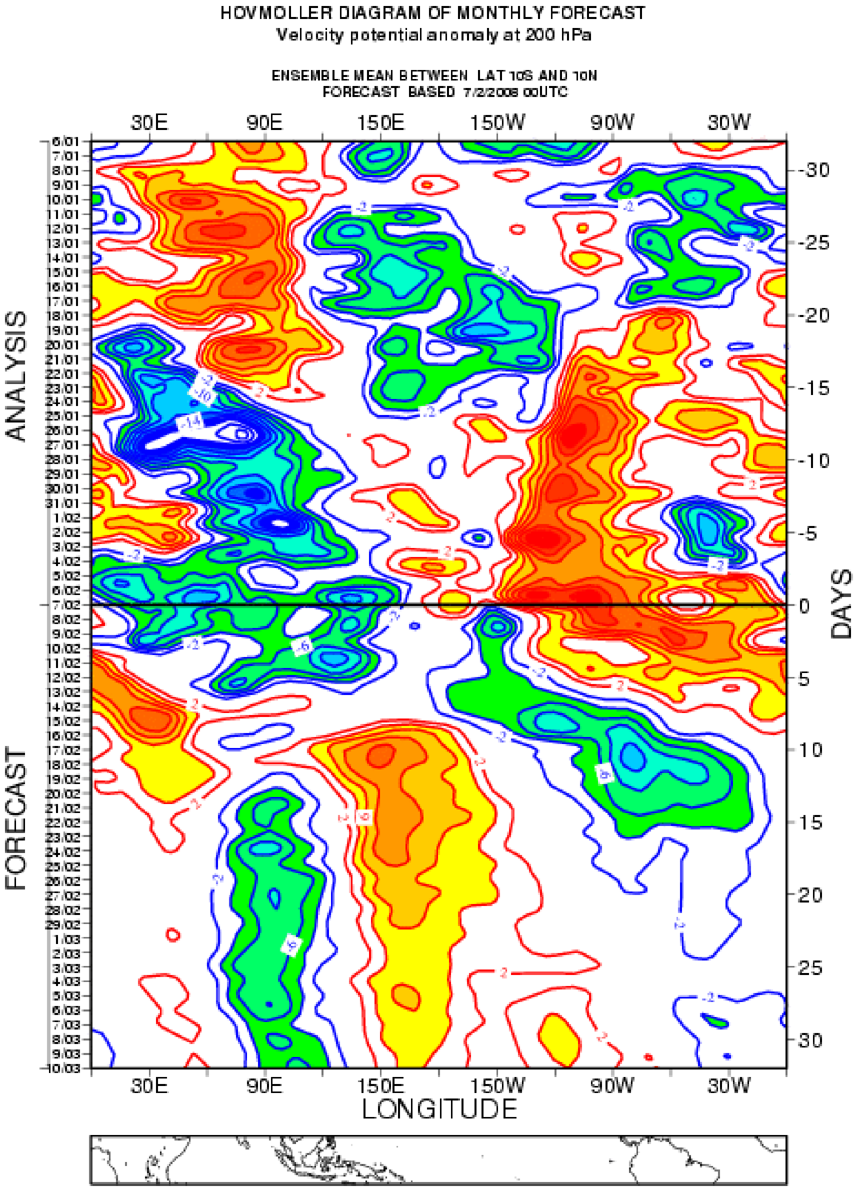
200hPa Velocity Potential Anomalies

February – March 2006

A typical MJO forecast from the ECMWF monthly forecast system in 2006

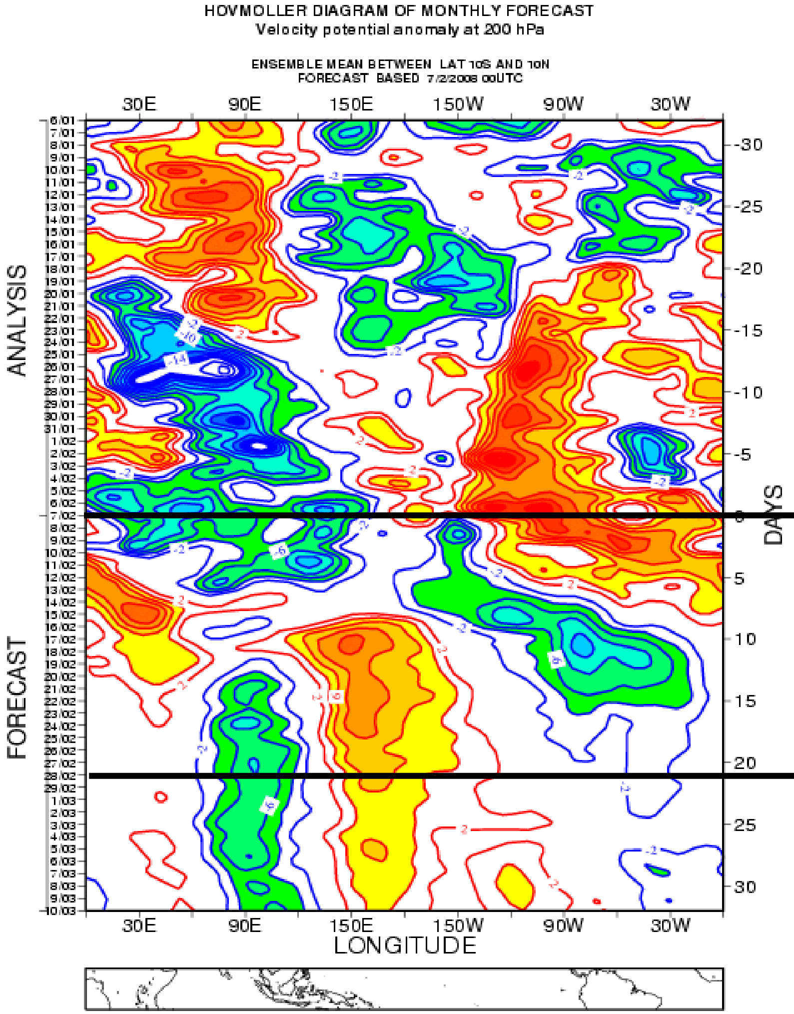
Hmmm…

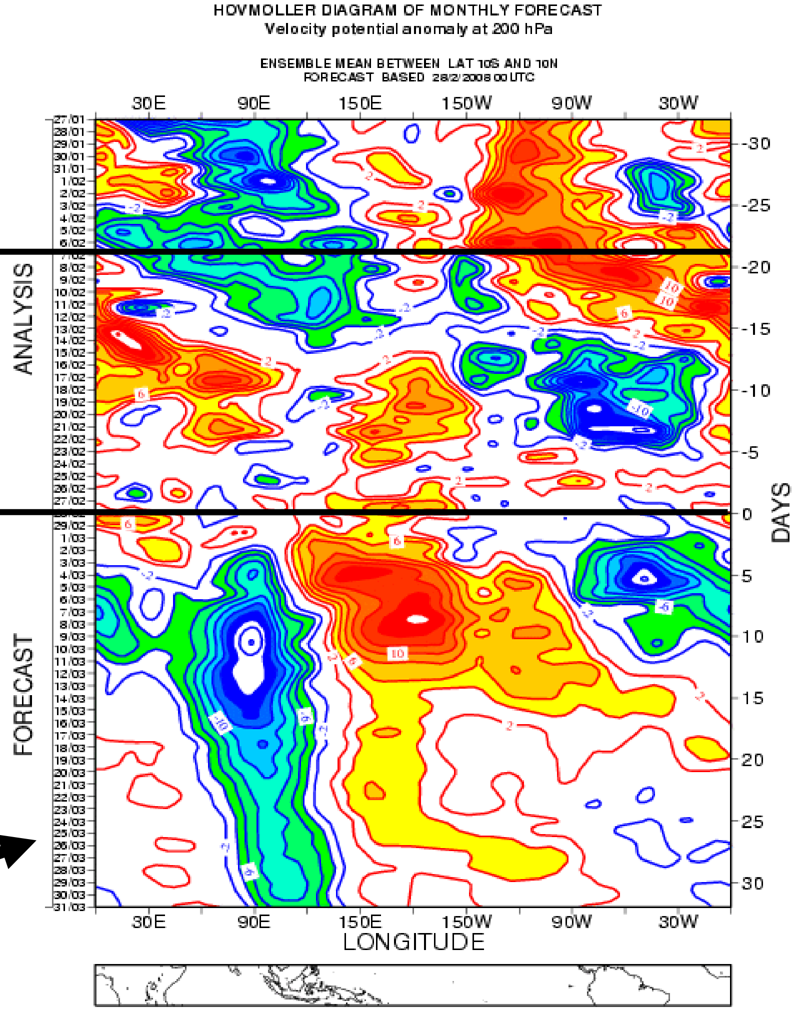
2008 – this February forecasts



FC from 7/2

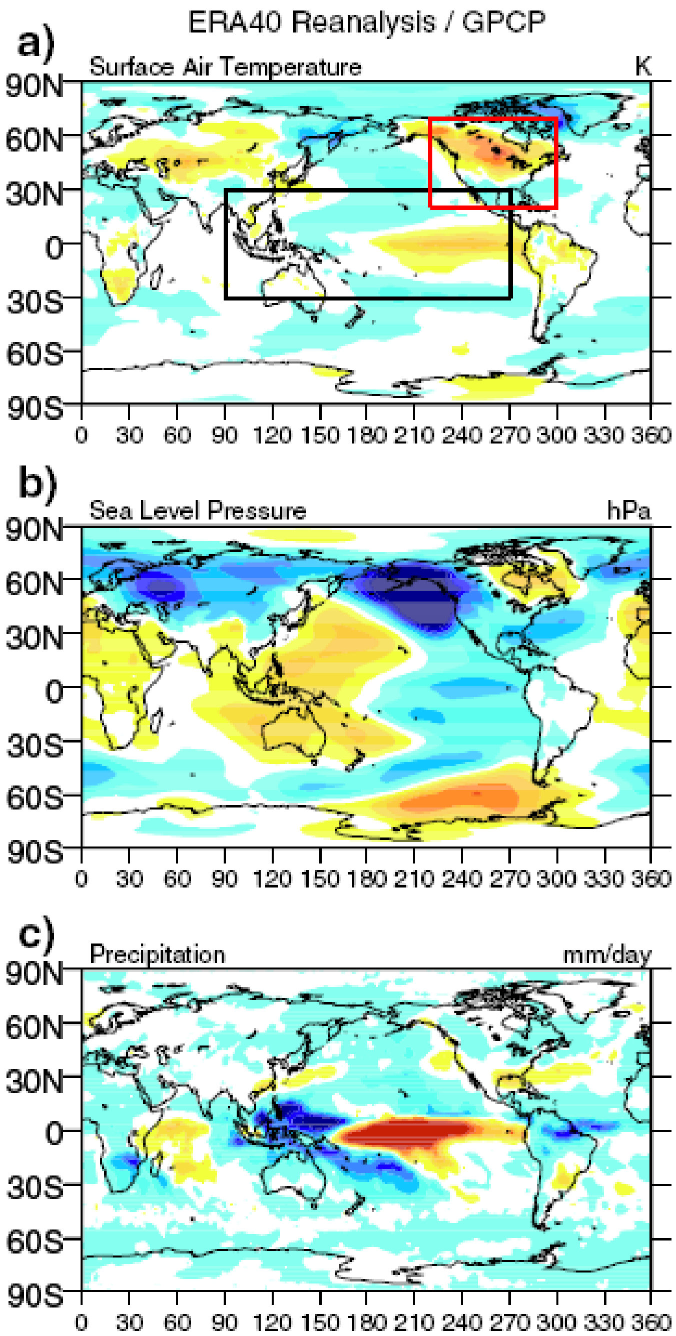
2008 – this February forecasts





FC from 7/2

FC from 28/2

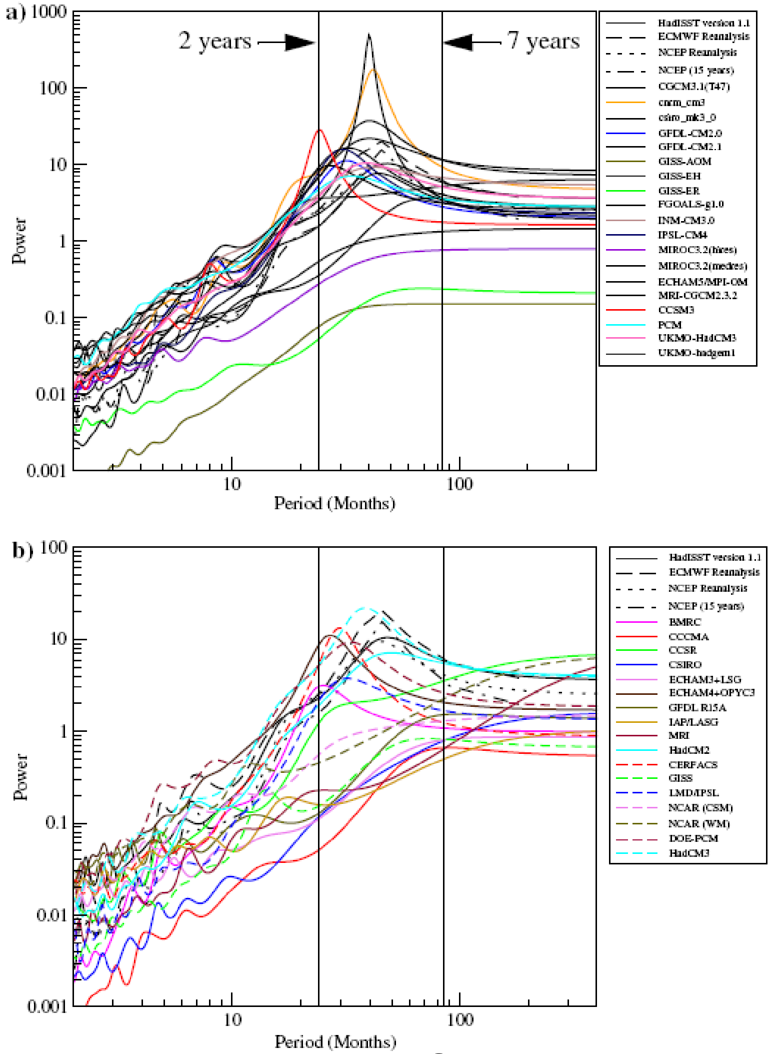


4. El Nino/ La Nina

- Affects the organisation of convection throughout the tropics
- Issues for regional modellers:
  1. Does the global model reproduce the frequency and magnitude of the El-Nino events?
  2. Does the global model reproduce the correct teleconnective convective response?

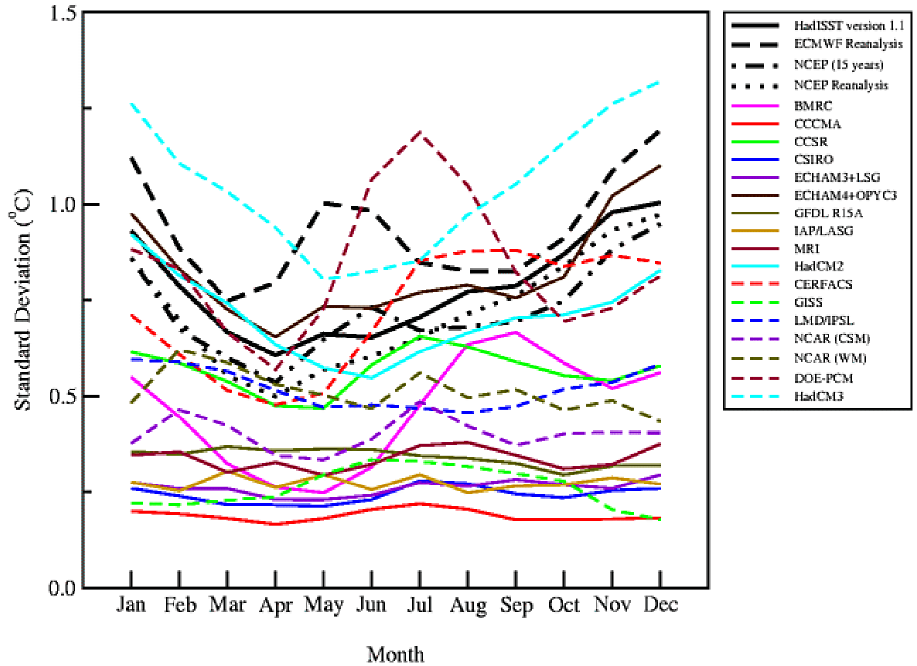
DJF warm anomaly composite from Rao and Sperber 2006

Variability between climate models



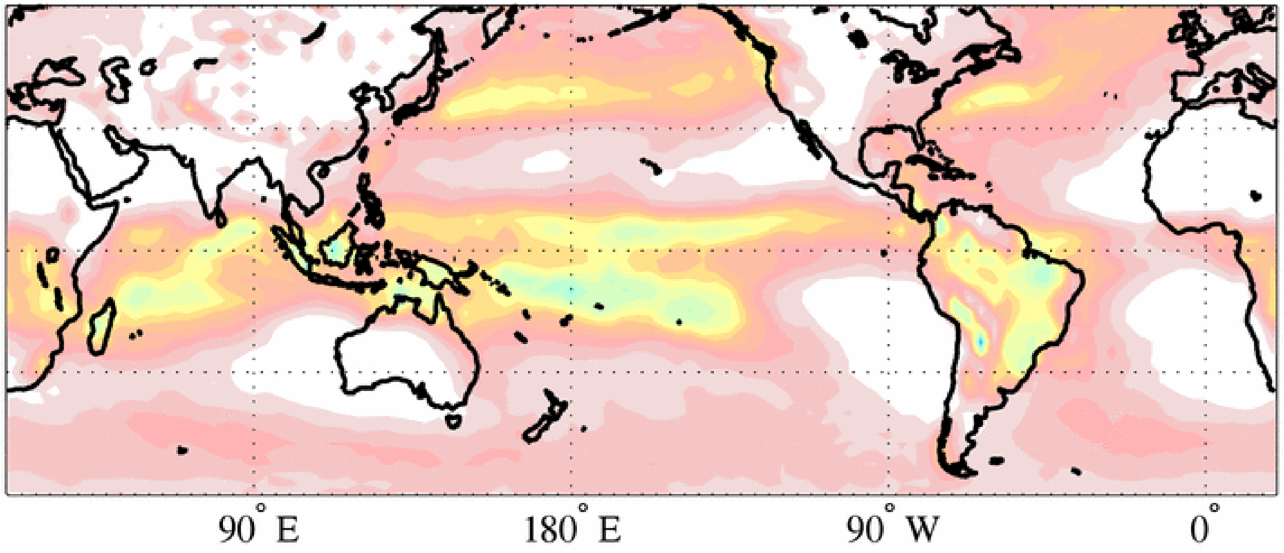
Power spectra of NINO3 T2m

Standard deviation of NINO3



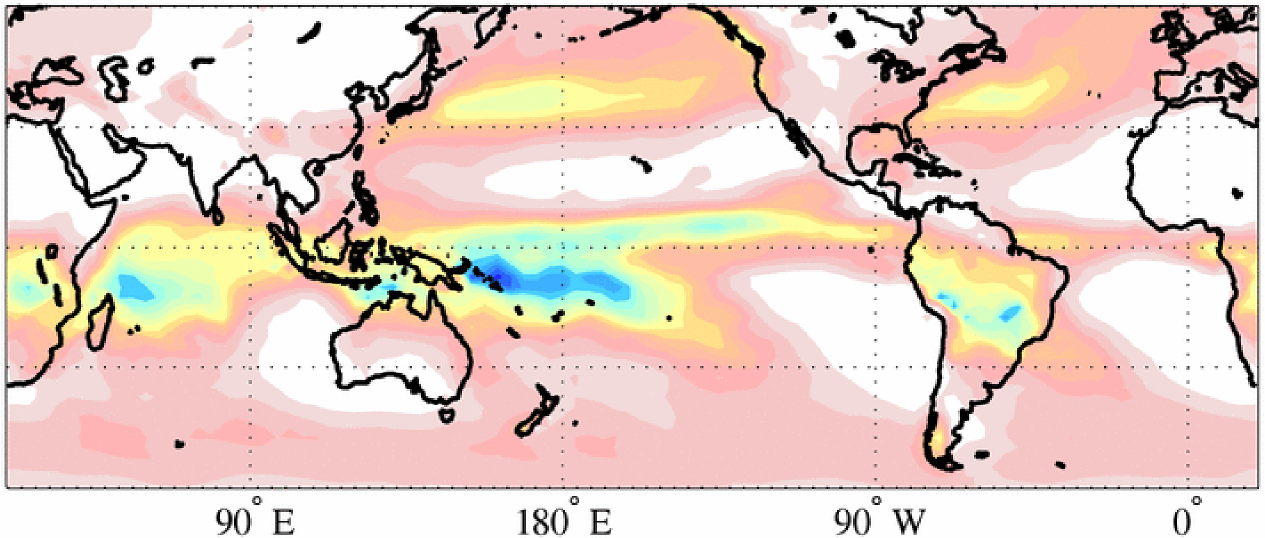
From: AchutaRao et al. 2002

Composite precipitation for DJF at peak of El Nino



NCEP Reanalyses

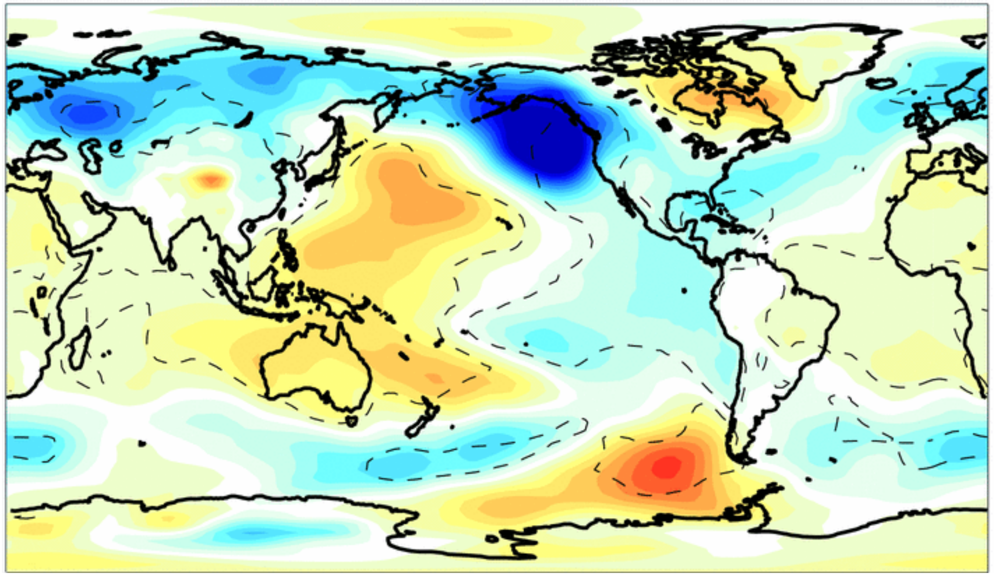
HadAM3



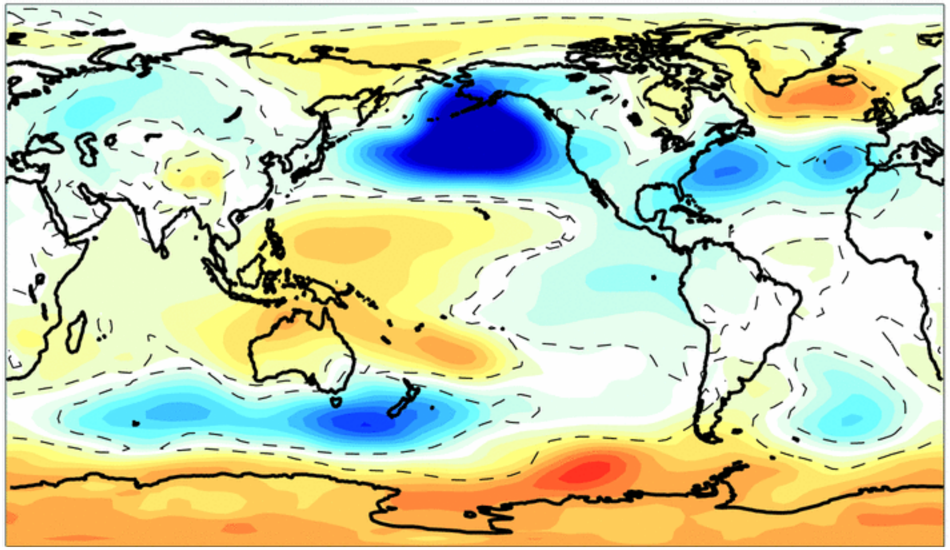
Note: compositing does not remove all of mean bias

Note eastwards shift of precipitation maxima in NCEP reanalyses with reduced rainfall over the Maritime Continent. HadAM3 retains the precipitation maxima over the West Pacific, leading to the lack of eastwards shift in the Aleutian Low.

Composite PMSL anomalies for DJF at peak of El Nino



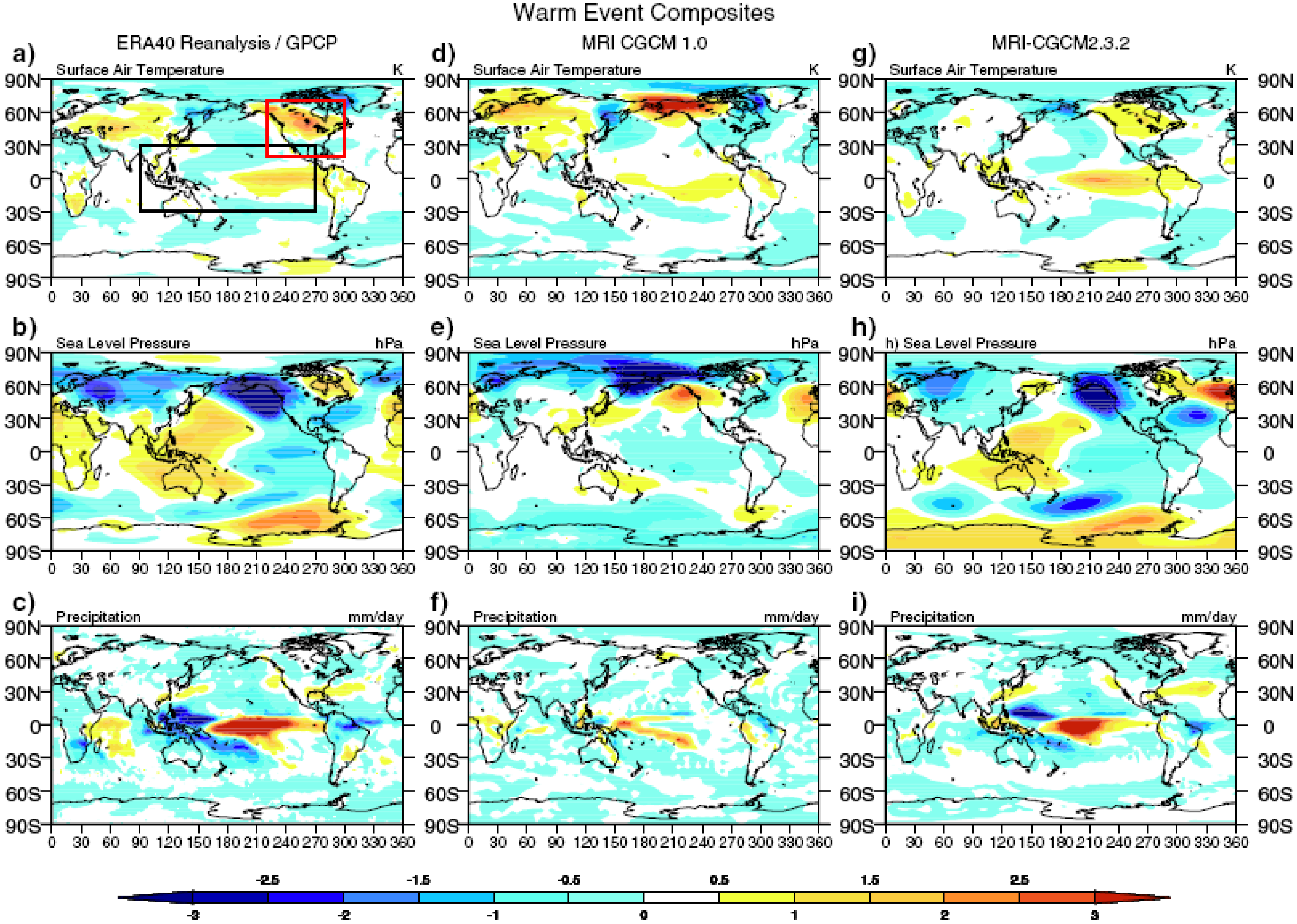
NCEP Reanalyses



HadAM3

Note good simulation of tropical anomalies – the Southern Oscillation. Anomalies over N. Pacific show major errors with an *in situ* deepening of the Aleutian Low in HadAM3 rather than a shift eastwards and the development of a ridge over the north west Pacific.

Rao & Sperber conclude that models have improved over the past decade



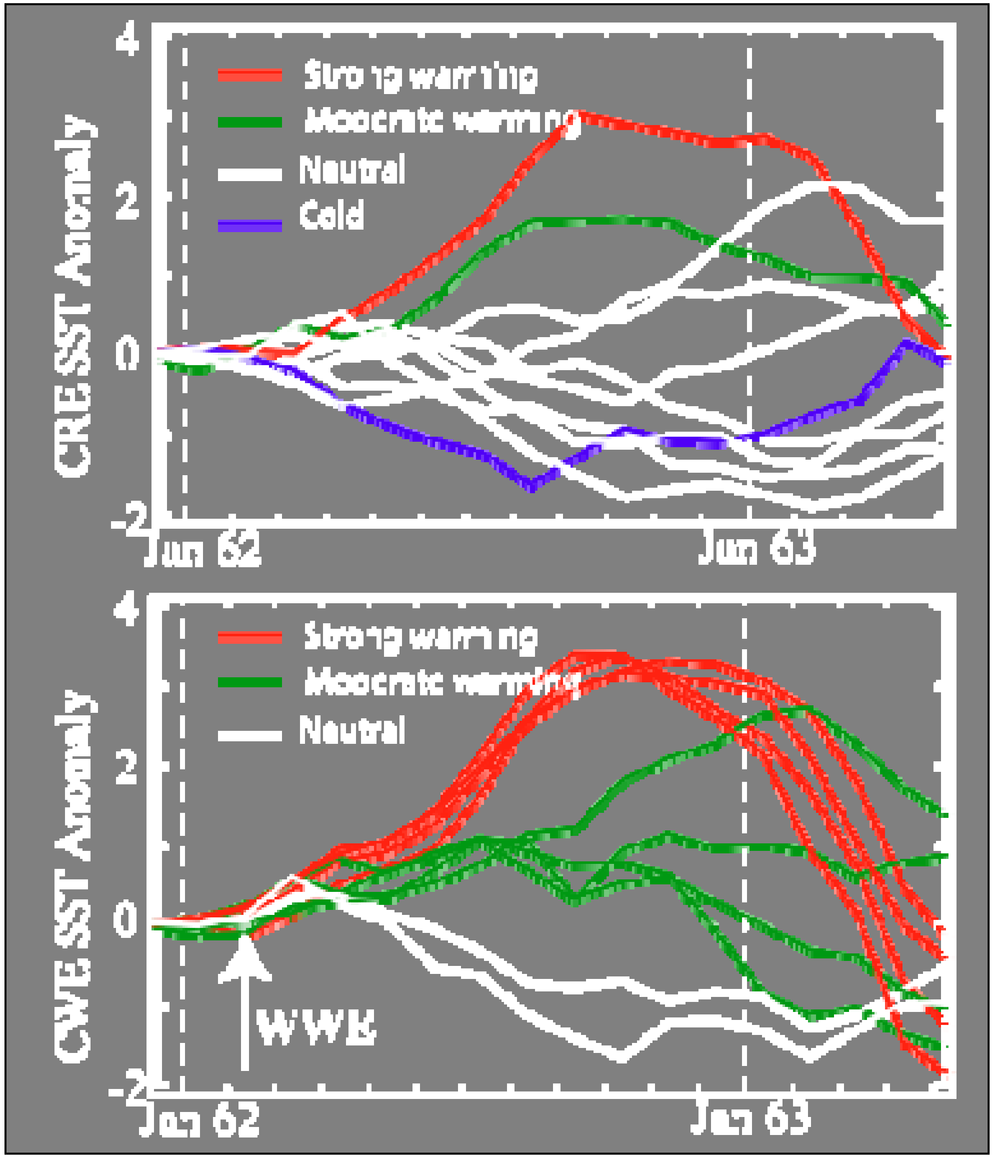
Impact of Westerly Wind Event on evolution of El Nino in HadOPA

Control ensemble:

- 1 strong warming
- 1 moderate warming

WWE ensemble:

- 4 strong warmings
- 4 moderate warmings

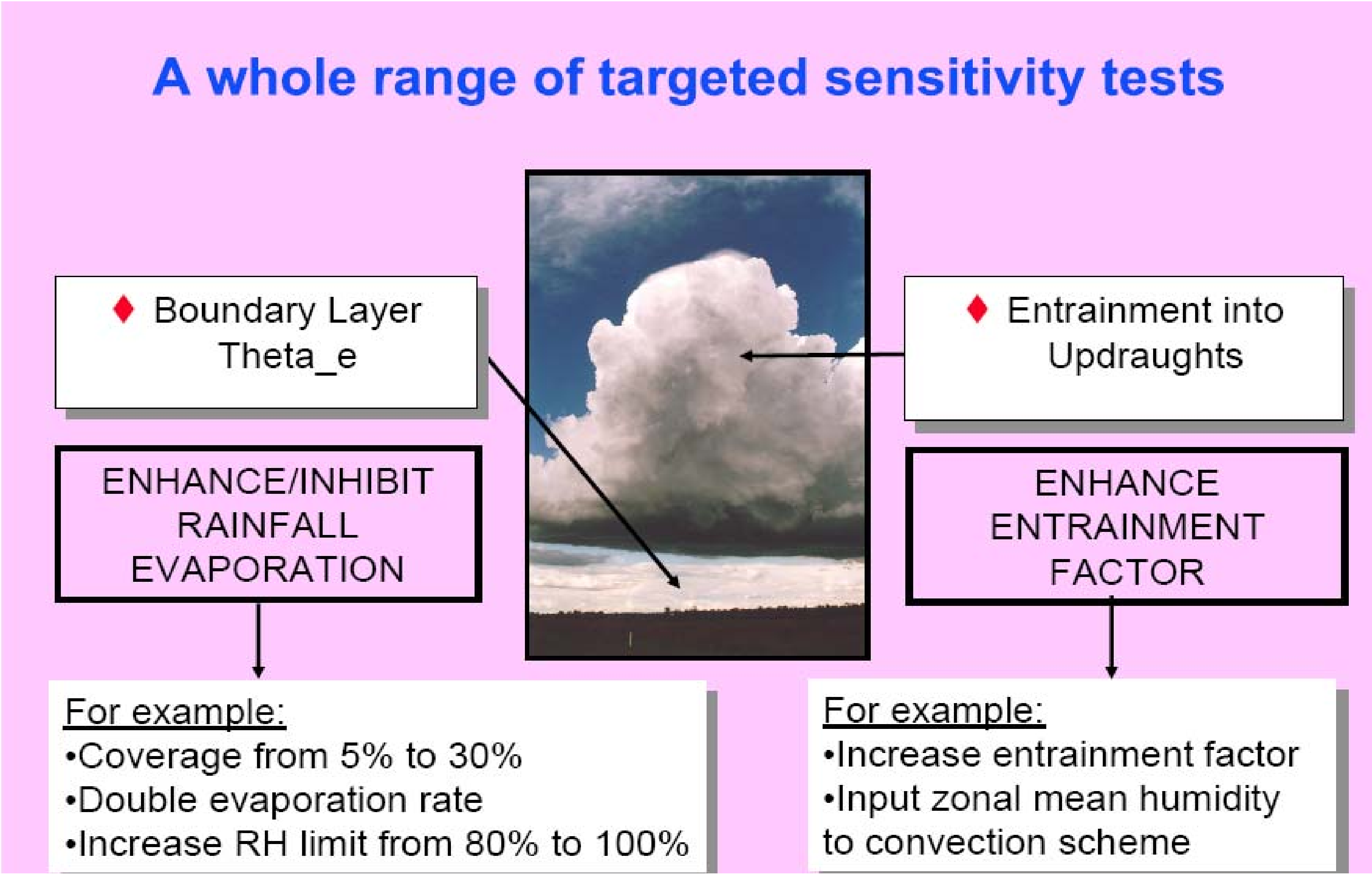


Lengaigne et al. 2005

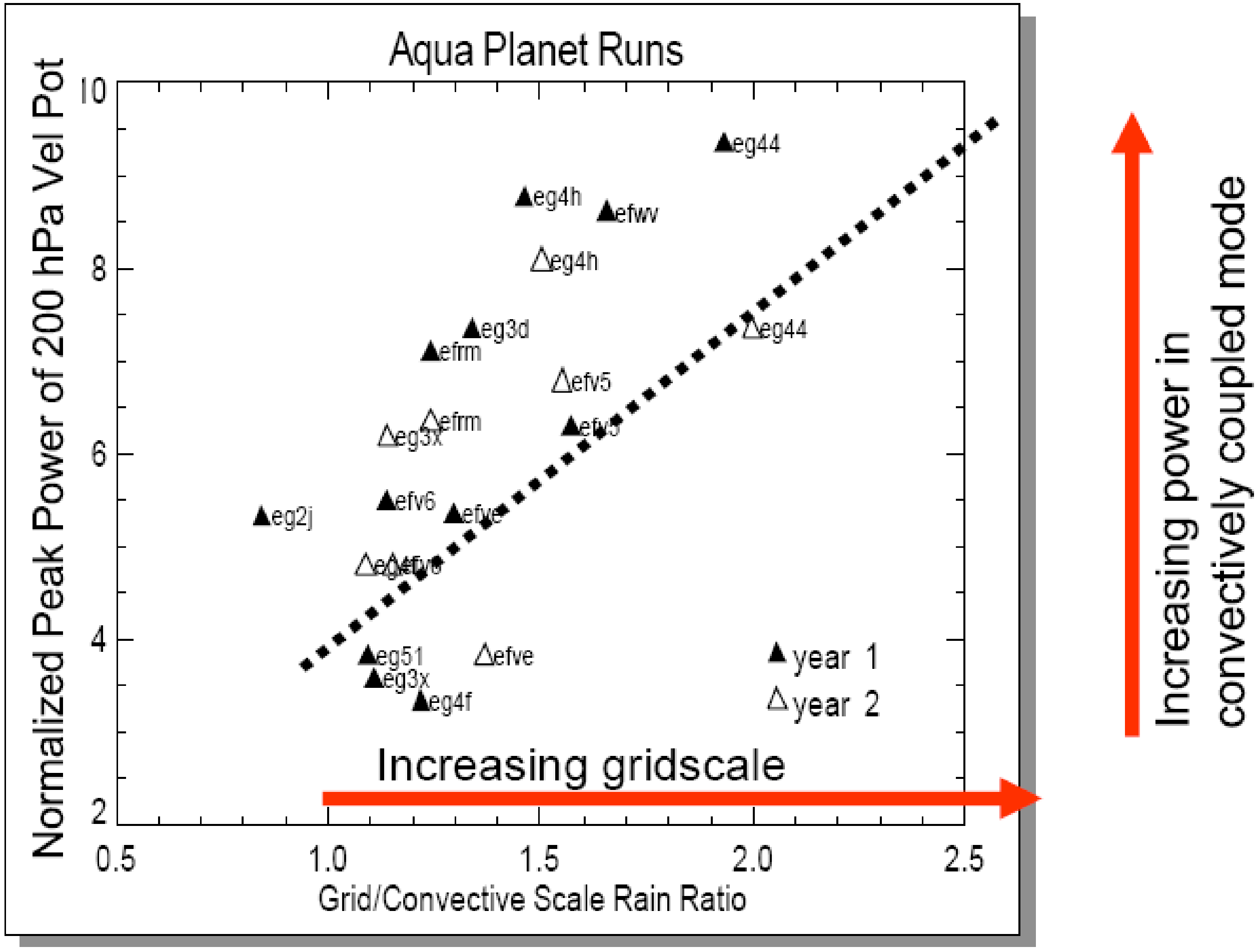
Discussion

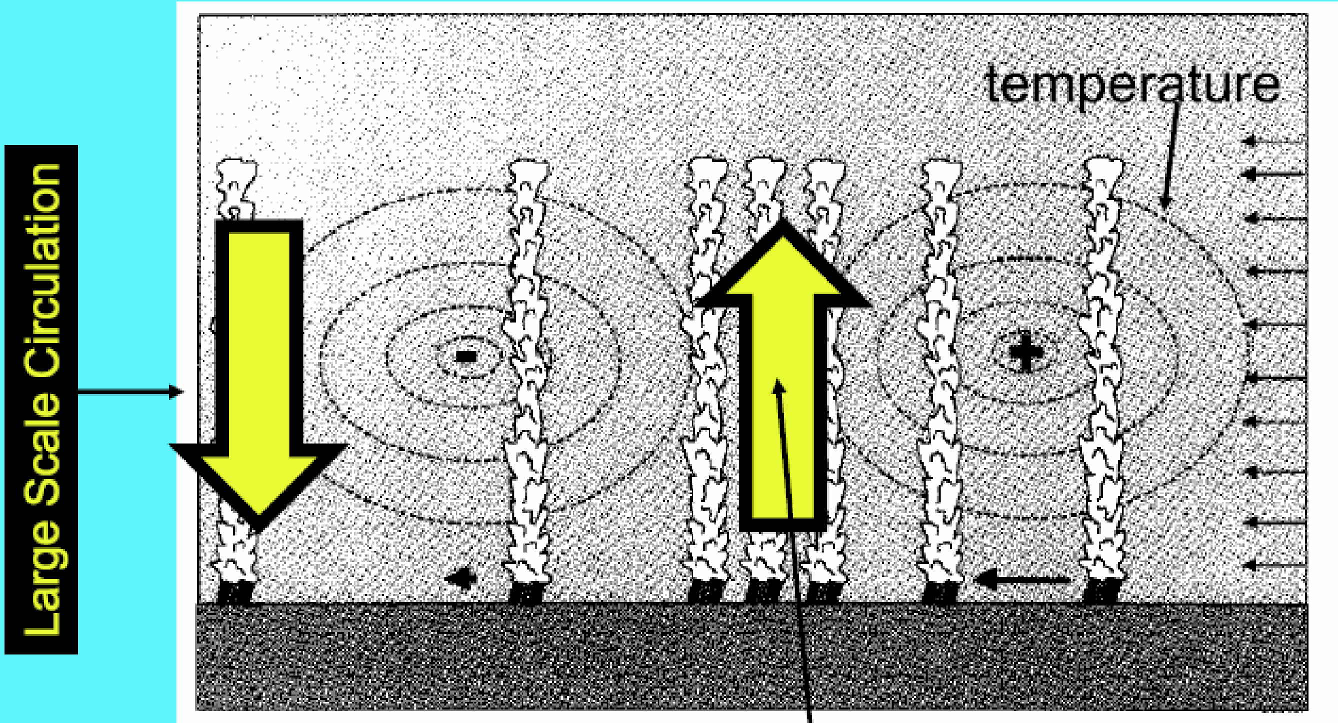
- Across temporal and spatial scales, tendency for global models to “damp” response
  - African Easterly Waves
  - Madden Julian Oscilliation
- Many possible causes:
  - Model diffusive
  - Lack of a physical feedback mechanism?
  - Are convective parametrization schemes acting to damp large-scale waves?

- A range of sensitivity tests were conducted using the ECMWF model
- The effect on the power in the MJO mode was examined

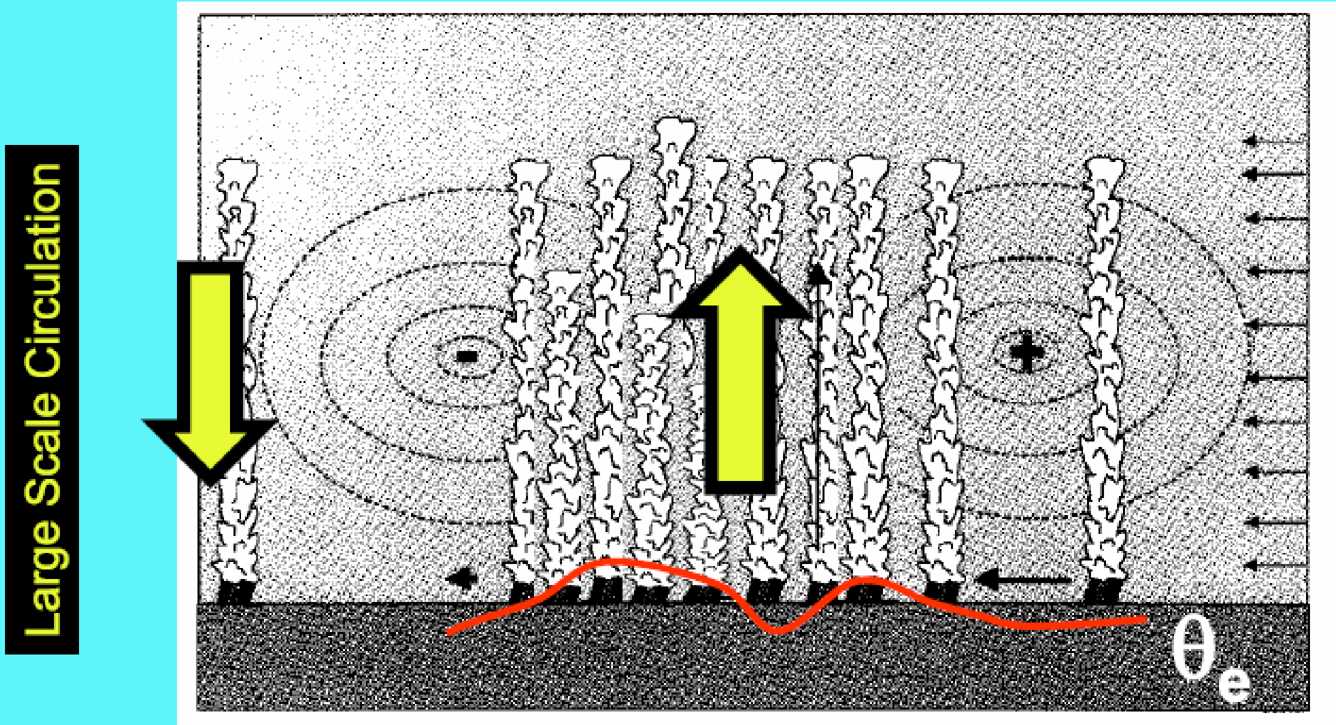


- The effect of the changes was to enhance or suppress the incidence of "grid-scale convection" at the expense of the convective parametrization scheme
- The balance between grid-scale and parametrized rain was correlated with the large-scale wave activity in the global model



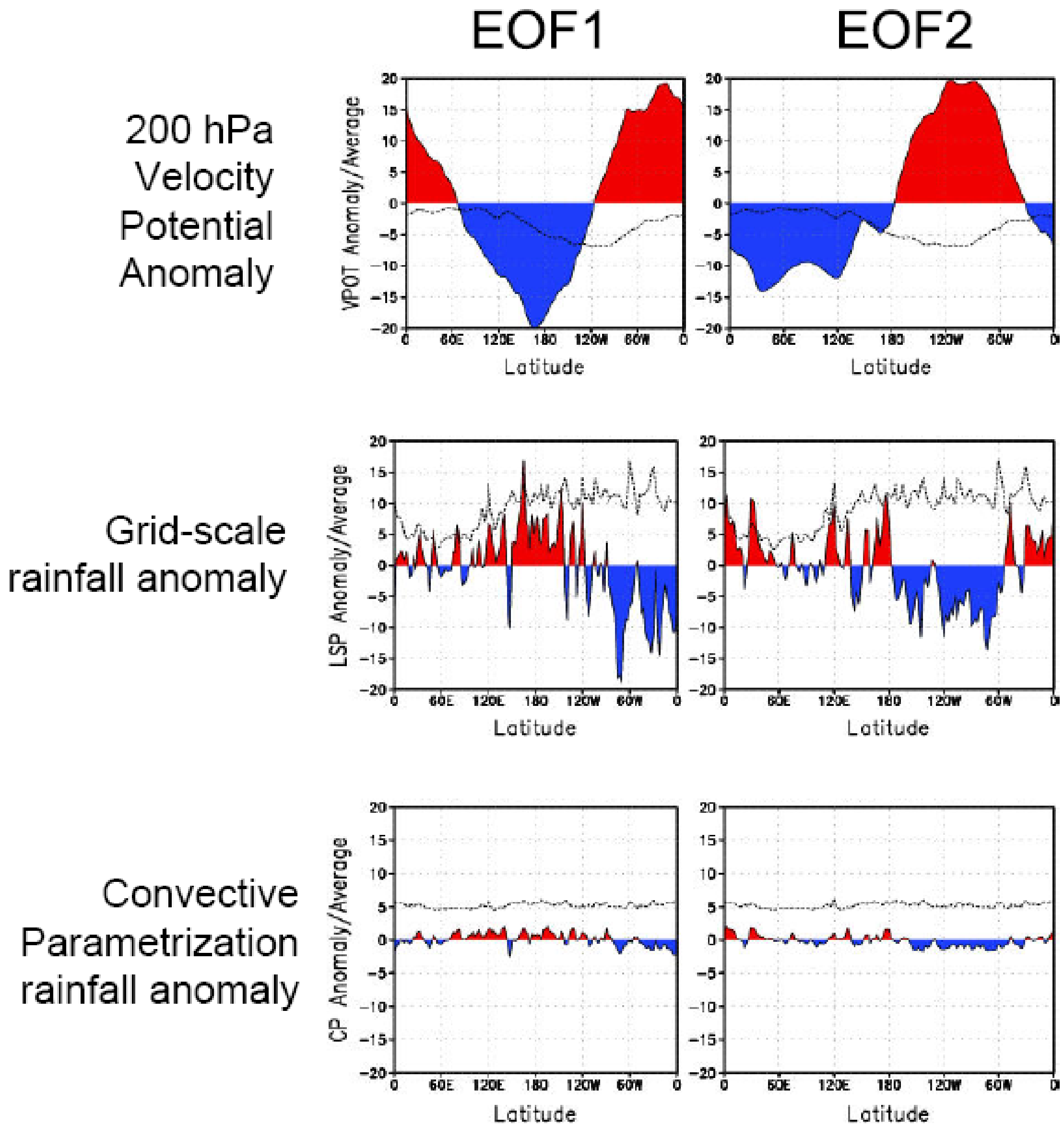


♦ Latent heating (from cloud scheme) directly in phase with upward motion by construction. Changes in cloud scheme have large influence on incidence of grid-scale convection

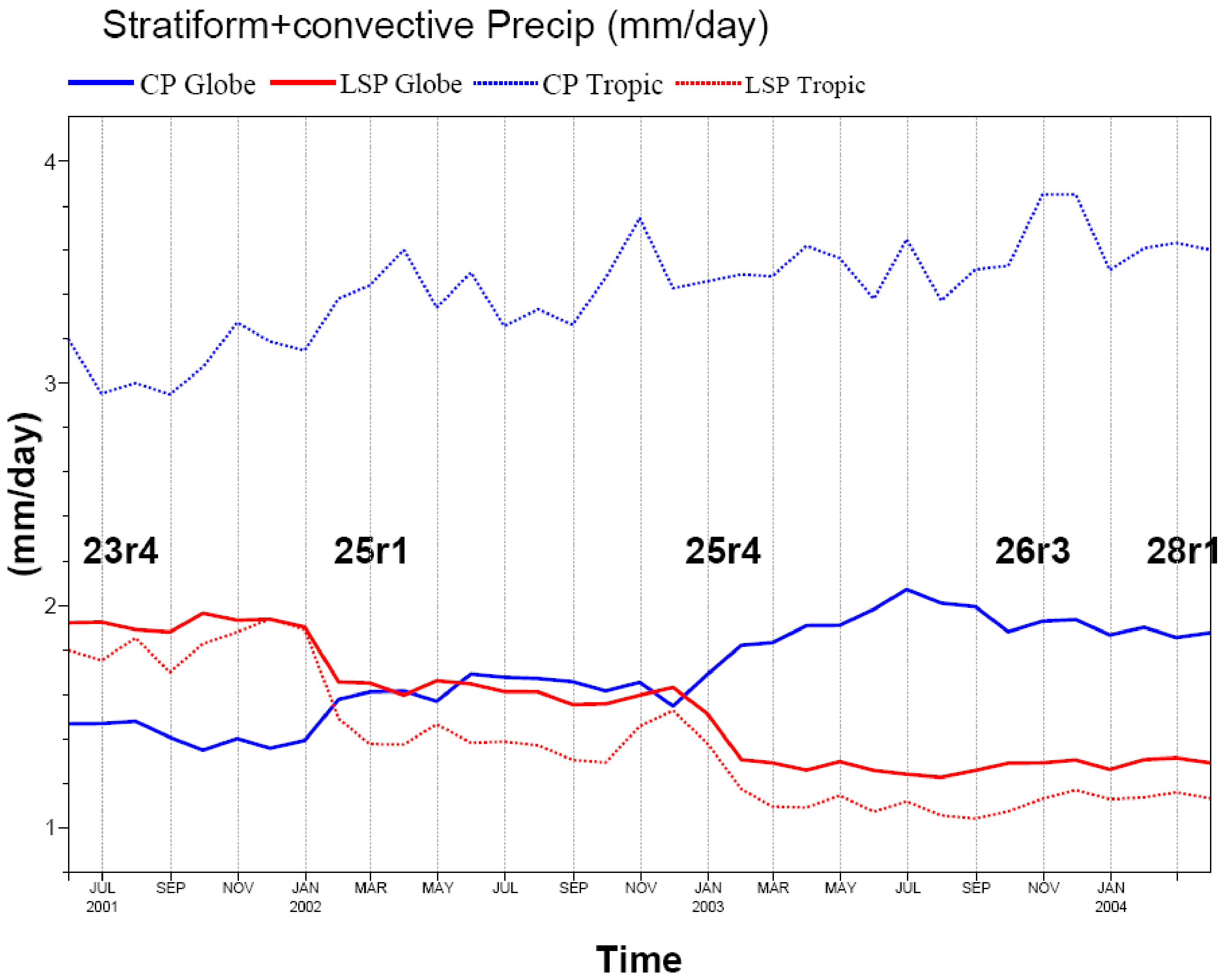


♦ The convection parameterization is not so constrained, and responds to *PBL* theta_e, CAPE, (humidity). Can provide heating out of phase, possibly damping the wave.

- This is clear when the grid-scale and convective parametrized precipitation anomaly are composited with the two leading EOFs describing the MJO-like variability
- The MJO-like wave has almost no correlation with the convective parametrization scheme



Balance highly sensitive to convective parametrization developments

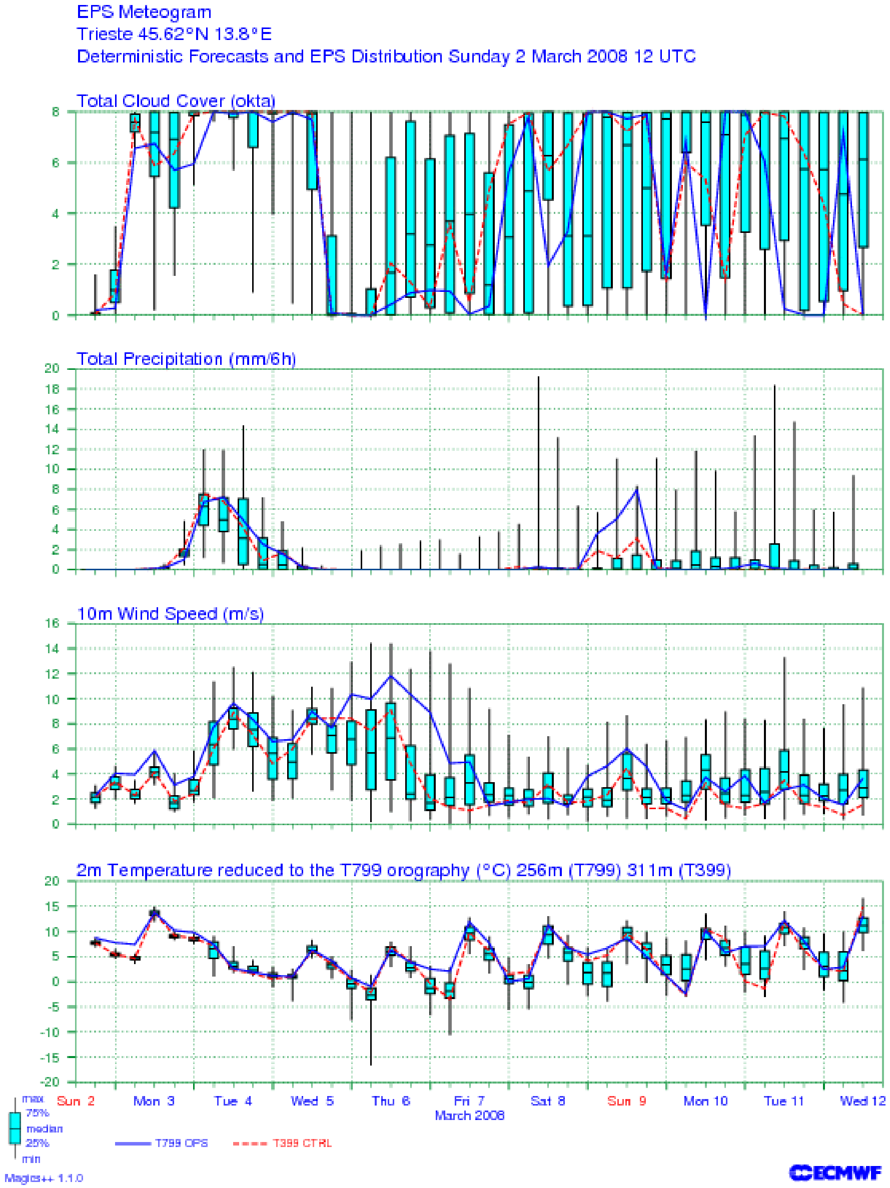


Current cycle 32r3, no grid-point storms in Tropics

Stratiform / convective ratio in tropics about 20/80

Conclusions

- Mean convective activity in a regional climate model domain is strongly constrained by the convergence defined by the boundary conditions
- Large-scale global model variability is thus crucial for regional climate model integrations
- Examined diurnal cycle, African Easterly waves, MJO, and El-Nino response in global NWP, and atmosphere or coupled climate models: Much variability between the models! And a tendency to damp responses? (convective parametrization?)
- POSITIVE OUTLOOK: There does seem to be a tendency for recent improvements in many models.
- POSITIVE OUTLOOK: compared to 10 or 15 years ago there is much more emphasis on validating inter/intra seasonal variability in global NWP/climate models. Including these metrics will accelerate improvements.



Trieste
Courtesy of ECMWF T799 (25km) deterministic forecast